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Journal
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Devoted to Science and the Mechanic Arts

Vol. 210 AUGUST, 1930 No. 2

THE REFLECTION OF HYDROGEN ATOMS FROM LITHIUM FLUORIDE.

BY

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ABSTRACT.

BARTOL RESEARCH FOUNDATION
Communication No. 47.

The paper describes the phenomena associated with the reflection of a sharply defined beam of hydrogen atoms from a crystal of LiF. Of primary interest is the fact that the atoms show interference effects in agreement with the wave mechanics theory and plane grating diffraction patterns are photographed. Evidence of the thermal agitation of the surface ions is obtained from the diffuse reflection which surrounds the specular beam.

The Schrödinger wave equation for the motion of a free particle of mass m is

$$\nabla^2\psi - \frac{4\pi mi}{h}\frac{\partial\psi}{\partial t} = 0. \qquad (1)$$

The solution of this equation corresponding to the kinetic energy $mv^2/2$ is

$$\psi = Ae^{2\pi i(\nu t - \sigma_x x - \sigma_y y - \sigma_z z)}, \qquad (2)$$

where

$$\nu \equiv \frac{mv^2}{2} \quad \text{and} \quad \sigma \equiv \frac{mv}{h}.$$

The motion of such a particle should have the characteristics of a plane wave of frequency ν and wave-length $\lambda = 1/\sigma$. The experiments of various investigators [1] have shown the validity of the wave theory of the motion of the free electron and have given values of the wave-length in agreement with the theory.

The free motion of atoms, ions and molecules should likewise have wave characteristics. In the case of the hydrogen atom, as the simplest example, the complete wave equation may be written in the form

$$\frac{1}{m}\nabla^2_{x,y,z}\psi + \frac{1}{\mu}\nabla^2_{\xi,\eta,\zeta}\psi - 8\pi^2\mu e\psi/mh^2\sqrt{\xi^2+\eta^2+\zeta^2} - \frac{4\pi i}{h}\frac{\partial\psi}{\partial t} = 0, \quad (3)$$

where x, y, z, are the coördinates of the center of mass of the atom and ξ, η, ζ the coördinates of the electron with respect to the center of mass. If m_- and m_+ are the masses of electron and proton, m and μ have the significance

$$m = m_- + m_+ \qquad \text{and} \qquad \frac{1}{\mu} = \frac{1}{m_-} + \frac{1}{m_+}.$$

Equation (3) is solved by

$$\psi = U_1(x, y, z)\, U_2(\xi, \eta, \zeta) e^{2\pi i E t/h},$$

where E may have a continuous set of values and represents the total energy. U_1 and U_2 must satisfy the equations

$$\nabla_1^2 U_1 + 8\pi^2 m\beta U_1/h^2 = 0, \quad (4)$$

and

$$\nabla_2^2 U_2 + \frac{8\pi^2\mu}{h^2}(\alpha - \mu e/m\sqrt{\xi^2+\eta^2+\zeta^2})\, U_2 = 0, \quad (5)$$

where

$$\alpha + \beta = E.$$

[1] Davisson and Germer, *Nature*, **119**, 558, 1927; *Phys. Rev.*, 30, 705, 1927; *Proc. Nat. Acad. Sci.*, **14**, 317, 1928; **14**, 619, 1928. G. P. Thompson, *Nature*, 120, 902, 1927; *Proc. Roy. Soc.*, **117**, 600, 1928; **119**, 651, 1928; **125**, 352, 1929; *Phil. Mag.*, **38**, 939, 1928. E. Rupp, *Ann. d. Phys.*, **85**, 981, 1928; **1**, 801; 1929, **1**, 773, 1929; *Zs. f. Phys.*, **52**, 8, 1928. S. Kikuchi, *Jap. Jour. Phys.*, **5**, 83, 1928. H. E. Farnsworth, *Phys. Rev.*, **34**, 679, 1929. D. C. Rose, *Phil. Mag.*, 6, 712, 1928. S. Szczeniewski, *Comptes Rendus*, **187**, 106, 1928.

The values of α are limited to the eigenwerte of (5) which is the equation satisfied by the eigenfunctione of the hydrogen atom. Hence values of α are to be interpreted as the energy values of the stationary states of a hydrogen atom in the system of axes in which the center of mass is at rest, and the remainder, β, of the total energy represents the kinetic energy $mv^2/2$ of the center of mass. Equation (4) is satisfied by

$$U_1 = e^{2\pi i(\sigma_x x + \sigma_y y + \sigma_z z)}, \tag{6}$$

where

$$\sigma_x^2 + \sigma_y^2 + \sigma_z^2 = \sigma^2 = \frac{2m\beta}{h^2} = \frac{m^2v^2}{h^2}.$$

In the x, y, z coördinate space the ψ function of the atom therefore, has the form of a plane wave of wave-length $\lambda = h/mv$.

In the case of more complex atoms or molecules similar considerations should lead to the same conclusion; that the motion of the center of mass may be represented by a plane wave in three-dimensional space.

Experiments designed to show the wave characteristics of free atoms and molecules have been tried by several investigators. Ellett and Olson [2] reflected cadmium and mercury atoms from crystals of rock salt and found specular reflection. This might be regarded as the zero order diffraction beam but no higher orders were found. Knauer and Stern [3] reflected H_2 and *He* molecules from polished surfaces of steel and glass and found specular reflection at very small angles as would have been expected if the phenomenon were that of the reflection of waves of wave-length $\lambda = h/mv$ and the surface was rough to the order of 10^{-5} cms. These same molecules were found to be specularly reflected from cleavage surfaces of rock salt.

The writer reflected monatomic hydrogen [4] from rock salt crystals and found a sharply defined specular beam but it was surrounded by such an intense diffuse background, arising, for the most part, from atoms having a cosine distribution that, with the technique then used, it could not be said with

[2] *Phys. Rev.*, **31**, 643, 1927.
[3] *Zs. f. Phys.*, **53**, 779, 1929.
[4] JOUR. FRANK. INST., **206**, 301, 1928.

certainty whether diffraction bands were, or were not, present. The variation of intensity [5] of the specular beam with angle and crystal temperature were such as might be interpreted if the reflection were that of waves from a surface roughened by thermal agitation to the order of magnitude of the wave-length. If it was assumed that the roughness was of the same order as the lattice spacing of the crystal, the wave-length could be placed at about 10^{-8} cms., in agreement with the value of h/mv.

Recently Estermann and Stern [6] have investigated the reflection of *He* and H_2 from NaCl and LiF crystals and have found diffraction bands from the cross grating formed by the rows of similar ions on the surface of the crystal. The positions of the maxima of these bands were in practically complete agreement with the angles calculated for the first order diffraction of the most probable wave-length so that these experiments constitute a definite proof of the wave theory of atomic motions as outlined above.

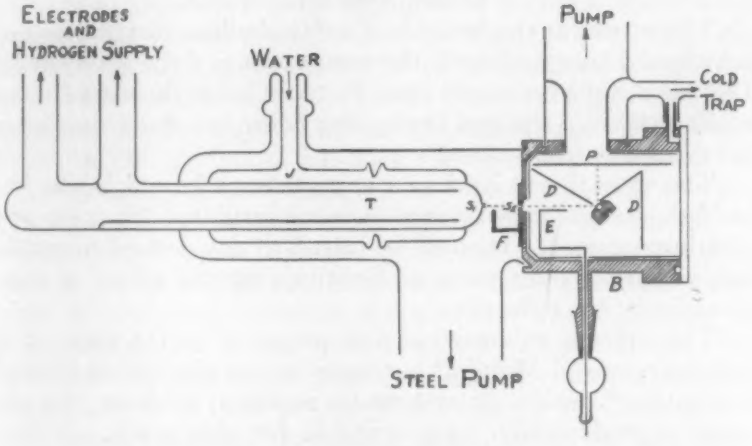
A continuation [7] of the writer's work on the reflection of *H atoms* from crystals revealed the fact that LiF crystals appeared to have several advantages over rock salt in experiments for investigating the wave character of the hydrogen atom. In the first place the specular beams from these crystals were very intense, amounting, from rough estimates, to from 50 to 100 per cent. of the incident beam at angles close to grazing, and to somewhat less at angles nearer the normal. Furthermore, LiF apparently does not reemit adsorbed atoms until after they have recombined to form molecules, and these can produce no effect on the MoO_3 detecting plate. The diffuse background, which masked the diffraction from NaCl, if it existed, therefore, does not appear in the case of LiF, but the plate records only the elastically reflected hydrogen atoms. Since, in experiments of this kind, there must always be a certain amount of adsorption, this property of the LiF crystal leads, at first sight, to the anticipation that hydrogen atoms might be used to show diffraction effects, more advantageously than atoms or molecules which undergo no change at the sur-

[5] JOUR. FRANK. INST. **207**, 629, 1929.
[6] *Zs. f. Phys.*, **61**, 95, 1930.
[7] *Phys. Rev.*, **35**, 650, 1930.

face when adsorbed. In addition to this consideration, the large values of h/mv for hydrogen atoms at room temperature (0.3 A. to 1.8 A.) give an a priori indication that these experiments have certain considerable advantages for detecting atom diffraction.

Experimental Arrangement.—The apparatus used in these experiments was the same as that formerly used in studying the reflection of hydrogen atoms from rock salt.[4] Atomic hydrogen from a Wood discharge tube was formed into a beam of rectangular cross section by means of two slits S_1 and S_2 (Fig. 1); S_1 was formed in the glass wall of the discharge

FIG. 1.



Apparatus for studying the reflection of hydrogen atoms from crystals.

tube by sealing into the glass a strip of copper foil which was afterwards removed with acid. This slit had the dimensions .16 mm. wide × 5 mm. long × 1 mm. deep. Because of its depth it had the advantage over a thin-jawed slit in directing a larger percentage of the atoms which passed through it into the second slit.[8] The pressure of hydrogen in the discharge tube was maintained at about 0.2 mm. Hg, and the region between the two slits was exhausted by means of a four-stage steel diffusion pump to a pressure such that an inappreciable

[8] This is shown by the experiments of H. Mayer, *Zs. f. Phys.*, **58**, 373, 1929, and is predicted on the basis of the theory of the flow of gases through tubes.

number of scattered atoms passed through the slit S_2 into the brass box B in directions other than that of the beam. The small number of atoms which did enter B in this manner were prevented from striking the detecting plate P by suitable diaphragms D. The entire inner surface of the box and the diaphragms were coated with platinum black which was occasionally cleaned with chromic acid. During an exposure these surfaces were kept free from wax and grease vapors since these were adsorbed by a liquid air-cooled bulb which was inserted into one side of the box. The walls, therefore, were almost perfect catalysts for the recombination of the hydrogen atoms at their first impact and no trouble was experienced from spurious effects arising from stray atoms.

The atoms in the beam had a Maxwellian distribution of velocities corresponding to the temperature of the glass slit S_1. This must have been very close to 100° C., for the water in the cooling jacket J reached the boiling point in a short time after the discharge was started.

The crystal was held in a copper block in which was imbedded a tungsten resistance element insulated by mica and alundum cement. It could be raised to any desired temperature either for outgassing or for studying the effect of temperature on the reflection.

The LiF crystals were at first prepared by the method of Ramsperger and Melvin [9] but later by the simpler method of Kyropolus [10] which proved to be superior, at least, for the small crystals which were suitable for this work. A new crystal surface was used for each exposure and these were cleaved just before placing in the apparatus. This procedure was found to yield the best results though the ability of the crystal to reflect specularly persisted to some extent even after the crystal had been exposed to the air for a day or two. Before starting an exposure the crystal was heated to 700° C for the purpose of removing gas from its surface. Although this treatment was not always necessary to produce specular reflection, a more intense reflection was obtained after its application.

The detecting plates were of glass smoked with MoO_3

[9] *Jour. Opt. Soc.*, 15, 359, 1927.
[10] *Z. anorg. allgemein. Chem.*, 154, 308, 1926.

which was formed by burning a strip of metallic molybdenum in an oxidizing flame. A chimney over the flame, containing two wire gauze screens, facilitated in producing a uniform smoke cloud and the glass plate was held in this until it was nearly opaque to yellow light. On exposure to the reflected atoms a blue pattern appeared on the otherwise white surface of the plate as a result of the reduction of the MoO_3 to MoO_2 by the atomic hydrogen. These patterns were photographed through a Wratten Aero No. 1 filter which absorbed all light of wave-length shorter than 4500 Å. and gave good contrast between the blue pattern and the white background. The best photographic results were obtained when the MoO_3 plate was illuminated in such a way that the light which entered the camera lens had been scattered by the plate through an angle of about 120°. The photographic negatives were measured with a Koch and Goos microphotometer [11] adjusted to give a nearly linear light sensitivity. Tests were made on the method of smoking the detecting plates and on the photographic procedure which showed that no spurious effects were introduced at either of these operations. A "calibration" plate, exposed to a uniform atom beam in various places for different times, was photographed and measured by the same standard procedure as was used with the other plates and it was found that with short exposures the densitometer deflection was approximately proportional to the number of H atoms per unit area on the MoO_3 plate. It is, of course, realized that this relation cannot be very exact, for it is a well known fact that different degrees of "contrast" can be produced by altering the exposure and development of the photographic plate, but with the uniformity in the photographic practice which was used throughout this work, the deflection of the electrometer fibre may be assumed qualitatively proportional to the number of atoms per sq. cm. on the original plate although the precautions taken were probably not adequate to give quantitative intensity measurements accurate to better than 25 per cent.

The following table gives the important dimensions:

[11] *Zs. f. Phys.*, **44**, 855, 1927.

Slit S_1 0.16 mm. wide, 4 mm. long, 1 mm. deep.
Slit S_2 0.14 mm. wide.
Distance between S_1 and S_2 15 mm.
Distance between S_2 and the crystal 31 mm.
Distance between the crystal and the plate 15 mm.
Crystal 2 mm. wide × 4 mm. long.
Angular aperture of the beam 1° 10′.

THE EFFECT OF ION BOMBARDMENT ON THE SURFACE OF THE LiF CRYSTAL.

In the first work with the LiF crystals the specularly reflected beam was intense directly after the bombardment by hydrogen atoms was started but its intensity diminished rapidly and the beam disappeared entirely after an exposure of one hour to the hydrogen atom beam. This fatigue in in reflecting power was found to depend upon the electric field between the positive column of the discharge and the brass box, for when a change was made in the connections of the transformer which was used to excite the discharge in such a way as to increase the field which accelerated positive ions through the slit in the discharge tube to the box, the fatigue time was diminished to the point that it was impossible to observe *any* specular reflection, although previously the spot formed by this beam had appeared visible to the eye in less than a minute. After an exposure to the beam of an hour or more under these conditions the crystal acquired a brownish tinge over the bombarded area. Accompanying these effects a third phenomenon appeared which lead to a complete interpretation of the situation. If the crystal and the copper crystal holder were electrically insulated from the brass box, irregular fan shaped patterns appeared on the plate corresponding to a deviation of the beam at the face of the crystal of about 10°. Three facts were discovered which proved that this was not a true reflection. (1) Diaphragms inserted between the crystal and the plate showed that the entities responsible for the patterns had not passed over the line connecting the spots on the plate with the face of the crystal. (2) The positions of the patterns showed no regular dependence on the angle of inclination of the crystal. (3) The patterns appeared as long as the crystal holder was insulated even though no crystal was present. These facts pointed to

the theory that ions from the discharge tube were being drawn out by the strong electric field between the positive column of the discharge and the brass box, and that these were bombarding the crystal, thereby damaging its reflecting power and producing the brown discoloration. The charge accumulating on the crystal and crystal holder produced an electrostatic field which served to deflect other ions from the beam into the irregular patterns observed on the plate. This theory was completely established when it was found that if the ions were removed from the beam by means of an electrode E (Fig. 1) charged to 5,000 volts, the life of the reflecting power was increased to three hours or more. At the same time the irregular patterns disappeared and the crystal was no longer discolored by the exposure. Microphotographs of the crystal surface (Fig. 2) indicate that the cleaved crystal surface is made up of small facets parallel to the 100 planes of the lattice. After bombardment, however, the surface is irregularly rough as though the ions had smoothed off the edges of the facets. The energy possessed by a single positive ion after falling through 3,000 volts is sufficient to raise a cube 100 atoms on an edge to a temperature of 1000° C. and at this temperature its evaporation should be quite considerable. It seems probable that the observed effects can be accounted for in this manner.

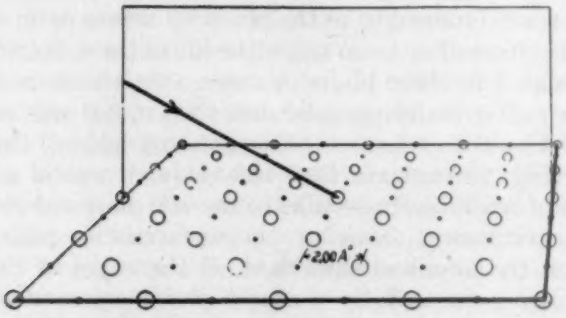
In some later work a copper fin F was attached to the brass box so that the accelerating field between the two slits was asymmetrical and the ions were pulled away from the slit S_2. This device, in addition to the electrode E, increased the time during which the crystal remained a good reflector to about six hours, but longer exposures than this were still impossible. Some recent work of Compton and Van Voorhis [12] suggests that protons, after striking a metallic surface with a velocity corresponding to 5,000 volts are neutralized but reflected with a large part of the original energy. Perhaps it is the bombardment of the crystal by such high velocity neutral atoms that is responsible for the remaining fatigue in reflecting power.

[12] Abstracts of the Washington Meeting of the American Physical Society, April, 1930.

THE REFLECTION OF ATOMS WITH THE INCIDENT BEAM IN THE 100 AZIMUTH.

In this work the crystal was oriented with respect to the incident beam as illustrated in perspective by Fig. 3. The plane of incidence was parallel to the cleavage edges of the reflecting surface and rows of alternately dissimilar ions ran parallel and perpendicular to the plane of incidence. If the perpendicular rows of ions are capable of acting as a line

FIG 3.



The arrangement of the atoms on the surface of an LiF crystal with respect to a beam incident in the 100 azimuth.

grating, a spectrum should appear dispersed in the plane of incidence corresponding to a grating space of 2.005 Å. The incident beam was of rectangular cross section and the detecting plate after exposure to the reflected beam, incident at 45°, had the appearance shown by the photograph of Fig. 4. Density graphs of this and of similar exposures at 30° and 60° from grazing are reproduced in Figs. 5, 6, and 7 and in the same figures are shown the calculated distribution of density for the first order diffraction bands. The scale of each of these calculated bands is adjusted in such a way that the area under this curve is just equal to the drafted specular beam diagram and the latter is constructed from the observed diagram in such a way as to represent the observed number of atoms in the specularly reflected beam. (The breadth of the drafted specular beam is calculated from the geometry of the slit system and its height is the same as that of the observed peak.) From a comparison of the height of the calculated curve with the specular peak it can be said, in the case of 30° incidence Fig. 5, that if the same numbers of atoms were going

into the first order band and into the specular beam, a bulge would appear in the observed density graph with an amplitude of 22 per cent. of the specular peak. On the contrary no such bulge can be observed at this point of the curve which cannot be accounted for by specks on the plate, etc. The smallest amplitude of the expected bulge which could be observed is about 2 per cent. of the amplitude of the specular peak and therefore it is concluded that *less than 10 per cent. as many atoms enter diffraction bands of this type as enter the specularly reflected beam.* Similar conclusions may be drawn regarding this type of diffraction for the angles of incidence of 45° and 60° from Figs. 6 and 7 respectively.

The conclusions of the preceding paragraph are based upon the assumption that all wave-lengths are diffracted with equal probabilities. If this is not the case and atoms of shorter wave-lengths (higher velocity) enter the diffraction beam in greater numbers than those of longer wave-length, it is possible that no maximum should appear, but instead a distribution such as is observed, tapering off on either side of the specular beam. Estermann and Stern [6] have found evidence of this phenomenon occurring in the case of the reflection of H_2 and *He* molecules and there is some reasonableness to an explanation along the lines of greater penetration into the surface fields on the part of the fast atoms.

A study of the reflection patterns at different temperatures, however, leads to a different explanation of these diffuse bands which accompany the specular beams.

THE EFFECT OF THE TEMPERATURE OF THE CRYSTAL ON ITS REFLECTION OF ATOMS.

When plane waves are reflected from a surface which is irregular to the order of the wave-length the reflection consists of a specular beam surrounded by a diffuse band having a maximum of intensity in the specular direction. Figure 8 shows the type of angular distribution pattern which is obtained in the case of the reflection of light waves from a roughly polished surface of nickel at 45° incidence. In this case the mean vertical displacement of the actual surface from the average surface plane was found to be about 0.0003 mm. or about ½ wave-length. (This estimate is based upon

the fluctuations in the reading of an optical lever having one pointed leg, as it was moved about on the surface, and from a microscopic examination of the surface.)

This distribution of the energy of reflected light is very similar to the distribution of atoms reflected from the LiF crystal as illustrated in Figs. 5, 6 and 7, and the resemblance suggests that the diffuse atom reflection is likewise caused by an irregular surface roughness of the crystal. By analogy with the optical scattering pattern of Fig. 8 we expect the mean displacement of the surface ions from the average plane of the surface to be somewhat less than ½ of the atom wavelength; that is, in the neighborhood of .2° Å. (The atom pattern is somewhat sharper than the light pattern.) A displacement of this amount can doubtless be accounted for on the basis of the lattice theory as the amplitude of the thermal motions of the surface ions, although it is known that the ions in the interior of the crystal oscillate through somewhat smaller amplitudes.

Further and more conclusive evidence that the diffuse reflection of atoms from LiF is to be attributed to the thermal agitation of the surface ions, lies in a comparison of the distribution curves shown in Fig. 9. These give the angular distribution of atoms reflected at 45° incidence, with the crystal maintained at various temperatures. The lowest curve corresponds to 300° K. the middle curve to 600° K. and the upper curve to 900° K. In order to reproduce all three curves in the same figure the specular peaks have been cut off but the scales are adjusted so that the specular peaks, if shown, would all be of the same height above the outer flat portions of the curves and hence the curves may be significantly compared. The increasing intensity of the diffuse band with higher temperatures is very striking and it indicates a considerable change in the surface roughness over this range of temperatures.

A DIFFRACTION PHENOMENON AT 10° INCIDENCE.

Although the reflection patterns from beams incident in the 10° azimuth failed to reveal diffraction maxima in the plane of incidence, one of these photographs reproduced in Fig. 10, shows distinct evidence of a slightly different type of

diffraction. This is the reflection pattern at 45° incidence from a crystal heated to 600° K. The features of the photograph referred to are the wing-shaped bands which run out on either side above the specular beam. Diffraction beams of this type are to be expected from the complete theory of diffraction from a crossed grating but the fact that they are relatively intense as compared with the bands discussed in the last section, is a matter of considerable interest and one which was not easily predicted. The great intensity of these bands indicates that the rows of similar ions constitute a more important grating than the rows of alternately dissimilar ions, for, although the same patterns are predicted from either set of rows, the observed pattern is of a lower order if referred to the rows of similar ions. In the arrangement which was used for obtaining the plate reproduced in Fig. 10 the rows of similar ions lay at an angle of 45° with the plane of incidence and the incident beam made an angle of 45° with the plane of the crystal (Fig. 3). The angles between the two sets of rows of similar ions and the incident beam were therefore 60°.

The positions of diffraction beams are determined by the angles φ and θ which satisfy the grating formulæ

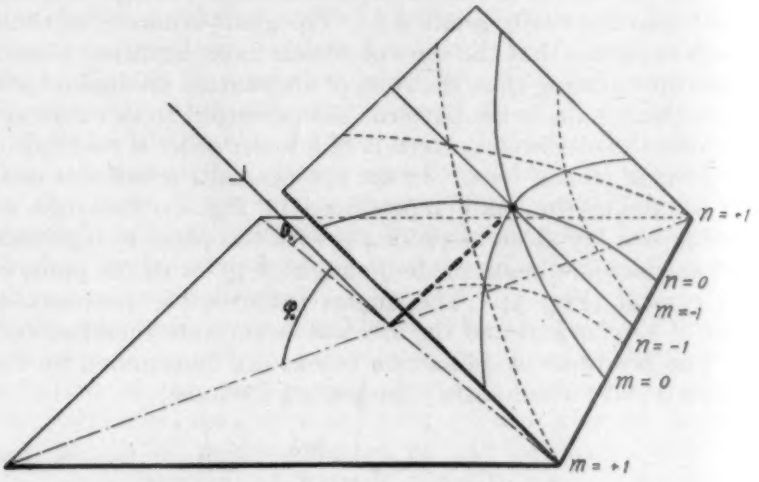
$$\cos \varphi_0 - \cos \varphi = \frac{m\lambda}{d}, \quad \text{and} \tag{7}$$

$$\cos \theta_0 - \cos \theta = \frac{n\lambda}{d}, \tag{8}$$

φ and θ being the angles between the diffraction beam and each of the sets of grating lines, which in this case are considered to be the rows of similar ions. The beams corresponding to $n = 0$, $m \neq 0$ and $m = 0$, $n \neq 0$ lie dispersed along the periphery of cones, $\varphi = \varphi_0$ and $\theta = \theta_0$. The intersections of these cones with the plane of the detecting plate are shown in perspective in Fig. 11. The analytical calculation of the intersections of these cones with the plane of the detecting plate is somewhat involved but they are easily constructed by the methods of orthogonal projection. The positions on the hyperbolæ $n = 0$ and $m = 0$ where it is predicted that the intensity should be a maximum are calculated from (7) and (8), using the value of the most probable wave-length of the

Maxwellian distribution $\lambda = 0.89$ Å. If d is chosen as the distance between adjacent rows of similar ions $d = 2.835$ Å, the value of φ corresponding to $m = 1$, $\varphi_0 = 60°$ is $\varphi_1 = 79° 16'$ and that corresponding to $m = -1$ is $\varphi = 35° 30'$. The intersections of these cones with the plane of the detecting plate as well as those corresponding to $n = 1$ and $n = -1$ are

FIG. 11.



The diffraction expected from the LiF cross grating. 10° incidence.

shown by the dotted lines of Fig. 11. The intersections of these dotted hyperbolæ with the hyperbolæ $n = 0$, $m = 0$ give the calculated positions of intensity maxima, neglecting corrections for the inclination of the plate to these beams. The loci of the intersections of the first order hyperbolæ, corresponding to different wave-lengths are the straight line and the parabola.

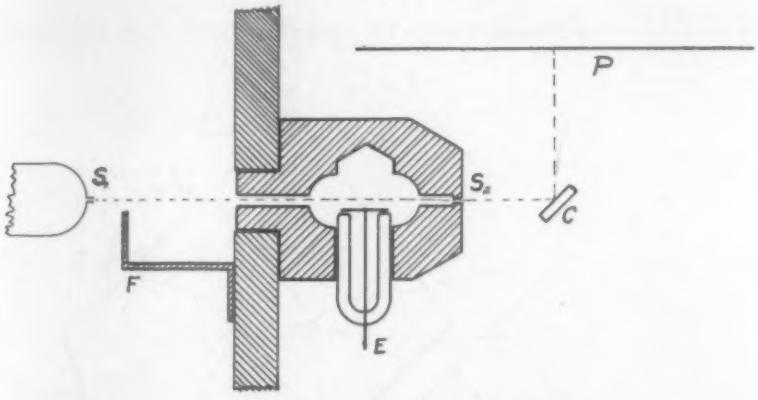
The arms of the hyperbolæ corresponding to $n = 0$, $m \neq 0$ and $m = 0$, $n \neq 0$ are the wing-shaped bands of Fig. 10. The positions of calculated maxima of intensity corresponding to the most probable wave-length of the Maxwellian distribution are indicated by the ink dots on the photograph. The branches corresponding to $n = 0$ $m = -1$ and $m = 0$ $n = -1$ are nearer grazing and are therefore dispersed more. For this reason and because these branches lie closer to the

plane of incidence and consequently become confused with the general diffuse reflection, they are indistinguishable in the photograph.

DIFFRACTION OF ATOMS INCIDENT IN THE 110 AZIMUTH.

To bring out the diffraction patterns to better advantage two changes were made in the apparatus. It seemed advisable to work now with a more symmetrical beam and hence the slit in the brass box was replaced by a pair of circular brass tubes, Fig. 12, between which the excess gas could be removed through a side tube provided for the purpose. An electrode used in applying an electric field across the beam to remove the ions was also inserted between the two tubes. This gave a nearly circular beam although the source slit was still of rectangular cross section.

FIG. 12.



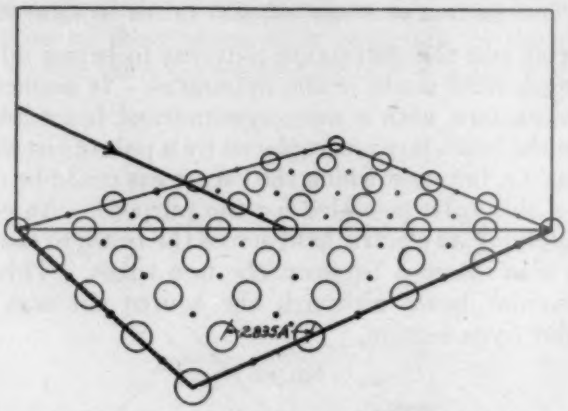
Slit system used to obtain a circular beam.

The crystal holder was also reconstructed so that the crystal now rested in a grove which was cut at 45° to the axis of rotation. The crystal was now oriented with respect to the incident beam as indicated by Fig. 13 so that the rows of similar ions ran parallel and perpendicular to the plane of incidence.

The positions of possible diffraction beams are again determined by the grating formulæ (7) and (8). In this case $\varphi_0 = 90°$ and θ_0 is the same as the angle between the incident beam

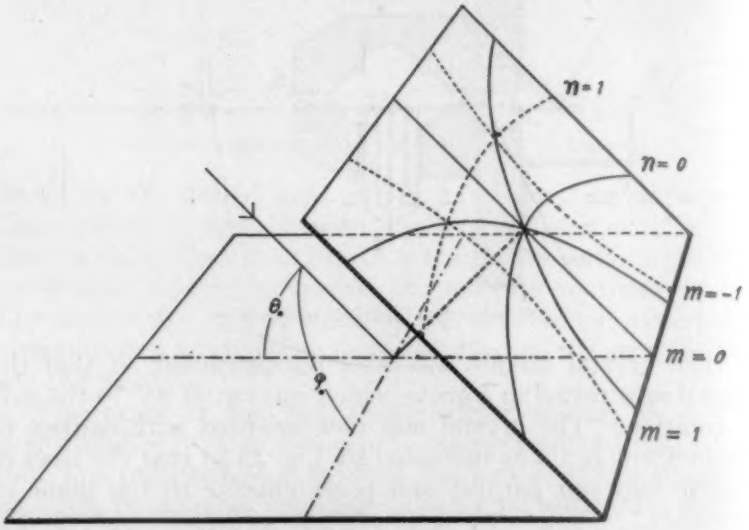
and the plane of the crystal. The geometrical arrangement for the case $\theta_0 = 45°$ is shown in perspective by Fig. 14.

FIG. 13.



The arrangement of ions on the surface of the LiF crystal with respect to a beam incident in the 110 azimuth.

FIG. 14.



The diffraction expected from the LiF cross grating—101 incidence.

The diffraction beams corresponding to $n = 0$ have $\varphi = \varphi_0$ and hence these lie in the plane of incidence. Those cor-

FIG. 2 *a*.

a. Freshly cleaved surface of LiF. × 300.

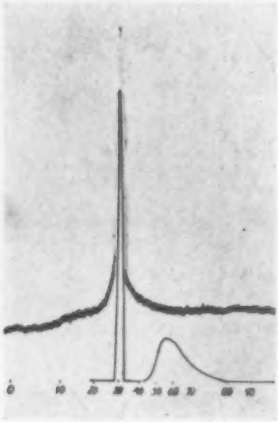
FIG. 2 *b*.

b. Same after 3 hour bombardment of atom beam without ions being removed.

FIG. 4.

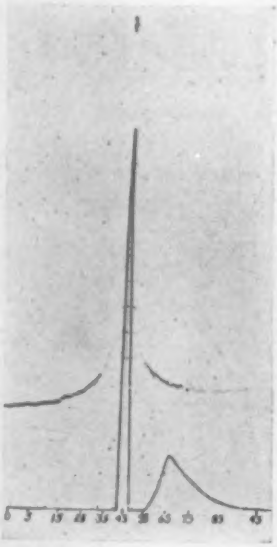
Photograph of detecting plate after exposure to a reflected beam of atoms.

FIG. 5.



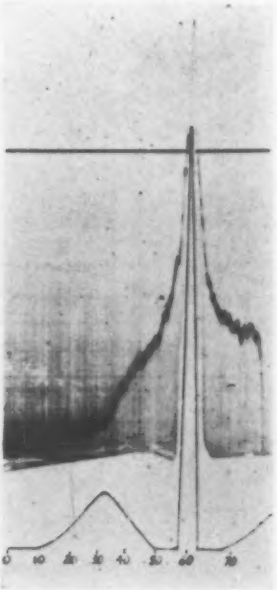
Distribution of reflected atoms incident at 30° from grazing.

FIG. 6.



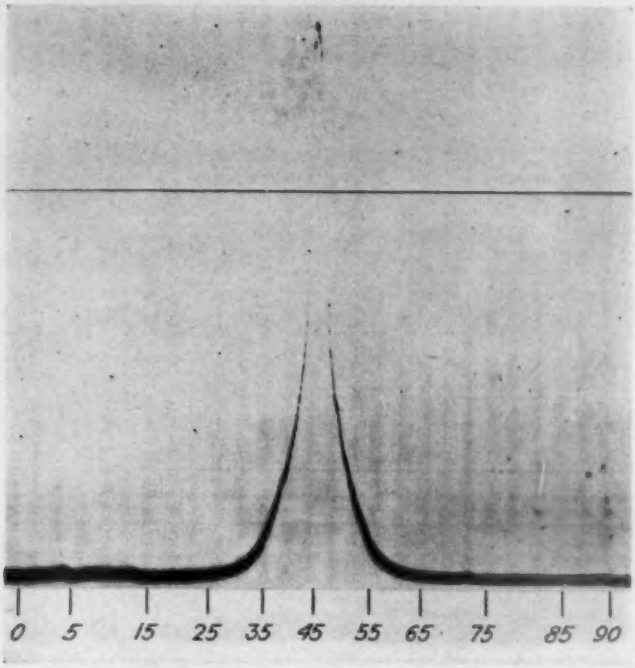
Distribution of reflected atoms incident at 45° from grazing.

FIG. 7.



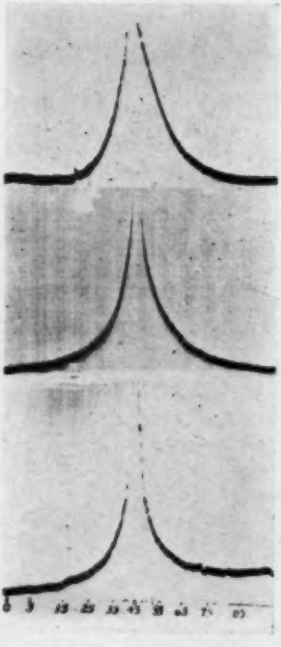
Distribution of reflected atoms incident at 60° from grazing.

FIG. 8.



Distribution of reflected light incident at 45° on a roughly polished surface of nickel.

FIG. 9.

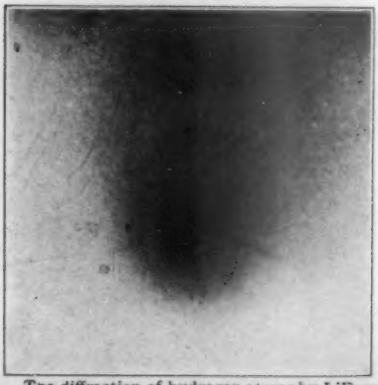


The variation of the intensity of the diffuse reflection with the temperature of the crystal. 45° incidence, upper 900° K., middle 600° K., lower 300° K.

FIG. 10.

Diffraction of hydrogen atoms by the cross grating formed by rows of similar ions on the surface of an LiF crystal.

FIG. 15.



The diffraction of hydrogen atoms by LiF—

responding to $m = 0$ have $\theta = \theta_0$ and lie dispersed along the periphery of a cone of angle θ_0 with axis along the line of the parallel rows of ions. The intersections of the plane of incidence and of the cone $\theta = \theta_0$ with the plane of the detecting plate are shown in perspective in Fig. 14. The dotted curves again represent the intersections of the cones $m = \pm 1, n = \pm 1$ corresponding to the most probable wave-length. The cone $n = -1$ lies below the plane of the crystal. In this case $\varphi_{\pm 1} = 71^\circ\ 42'$ and $\theta_{+1} = 66^\circ\ 51'$. The loci of the $n = \pm 1$ $m = \pm 1$ beams are in this case the pair of hyperbolæ which intersect in the specular beam.

Figure 15 is a photographic reproduction of the detecting plate after exposure to the reflected atoms with the arrangement as indicated in Fig. 14. The parabolic intersection of the cone $n = 0$ is clearly visible and there is a suggestion of the hyperbolæ $n = \pm 1, m = \pm 1$. The positions $\varphi = 71^\circ\ 42'$ are indicated by the dots and they agree well with the most intense portion of the parabola. The bands dispersed in the plane of incidence were considerably less intense than the parabolic bands though perhaps faintly visible on the original plate. The calculated position of maximum intensity on the side of the normal of the crystal is indicated by the dot and its proximity to the specular beam shows that the small intensity in this band cannot be accounted for on the basis of high dispersion though this explanation might be employed to account for the small intensity in the corresponding band on the opposite side of the specular beam. The intensity of the parabolic bands are such as to indicate that about one-tenth as many atoms enter one of these bands in the first order as enter the specular beam.

These photographs represent the first diffraction effects obtained with atomic hydrogen and it is anticipated that work in the near future will perfect the technique of photographing the diffraction beams to the point of making it possible to obtain all of the first and second order beams.

Before going to press patterns at normal incidence were obtained distinctly showing all of the first order beams ($n = 0$, $m = \pm 1$; $m = 0$, $n = \pm 1$) and very faintly the beams corresponding to $n = \pm 1$, $m = \pm 1$.

It cannot be claimed of this work that it represents a more

convincing proof of the wave character of a beam of atoms than does the work of Estermann and Stern for their work seems to be quite conclusive but it is satisfying to have the actual photographs of the complete diffraction patterns. Although the technique employed by Estermann and Stern is more difficult and would seem to be more liable to spurious effects than that which has here been employed it has the apparent advantage of being able to make direct quantitative intensity measurements along any particular branch of the diffraction pattern. This same end, however, can also be accomplished with the photometric technique which has here been described and it is hoped that this may soon be done.

It is a matter of philosophical interest that now from the experimental standpoint an atom is as much a wave as is a quantum of light.

It is a pleasure to acknowledge the help of Mr. C. K. Boyer who has assisted throughout the course of this work.

TRANSPORTATION DEVELOPMENT ON THE PACIFIC COAST.*

BY

PAUL SHOUP,

President, Southern Pacific Company,
San Francisco.

The first transportation along the Pacific Coast by other than natives was undoubtedly by the Russians. They had settled Alaska, or rather, taken possession of it in 1745. With the Aleuts from Alaska, they patrolled the Coast as far south as the northern part of California. Their principal occupation was fishing and sea otter hunting in the neighborhood of the kelp beds. They created early colonies in California north of San Francisco at Bodega and Fort Ross, which lasted only a few years. In San Francisco they had maintained a post, and it is altogether probable that the Russians would have added California to their northern possessions had it not been that the Commander-in-Chief of the forces was after a year recalled, leaving a Spanish wife behind, and returned to Russia, where he died.

In the meantime, the Spanish had undertaken their march northward from Lower California. Their pioneering was a mixture of Church and State. The Franciscan Friars, who founded the 21 Missions, were accompanied by soldiers. These 21 missions, the first of which was at San Diego, established in 1769, were strung northward along the Coast line to Sonoma, a point 40 miles north of San Francisco, a total distance in excess of 600 miles. With the rancherias that intervened they were such distances apart as to afford shelter and food for man and beast at the end of each day's journey. Transportation was then either on the backs of men or on muleback. There were no roads.

Early in the nineteenth century Mexico became independent, and California was likewise released from the rule of Spain, which had never been otherwise than nominal. During

* Presented at the Stated Meeting held Wednesday, January 15, 1930.

this period the traders from abroad coming around the Horn in sailing vessels went up and down the California Coast acquiring hides, tallow and pelts in exchange for the commodities that those traders brought with them. There being no roads, and the settlements being small, even of Indians, they were obliged to send men inland to advise the people of their approach. The population was largely Indian.

The total white population of California in 1840 was estimated at less than 400, but during the next ten years the increase was considerable as trade grew more extensive and the white people acquired more and more lands. The fertile well-watered lands of the State had been granted to Mexicans and Spaniards in very large holdings, and these grants today constitute original titles to a considerable part of the State.

DISCOVERY OF GOLD.

The discovery of gold in 1849 at Coloma changed the whole aspect of transportation and trade immediately. San Francisco became a flourishing city almost over night. Within four years it saw itself taking on the glory of Genoa or Venice at the height of their activities. The population of California in 1850, after the gold rush, was estimated at 100,000. People came from all quarters of the globe, but chiefly from the Eastern coast of the United States, either overland or via the Isthmus, or around the Horn. This gold discovery was not on any mean scale; the first mining was placer mining, the free gold being washed out of the rough gravel and sand of the gold-bearing streams. The pan with which the first prospector found the color of gold was replaced by the rocker, and then by more elaborate processes. Nearly 50 million dollars was taken out of the gold fields of California in the first year, or $500 for every inhabitant. No wonder, of course, that the imagination of the world was excited.

By 1853 San Francisco had become a real city, with 18 steamboats plying up and down the Coast, four of them as far as the Isthmus of Panama and two as far as San Juan in the South, and others to ports on the Pacific.

In February 1849 the first steamship of the Pacific Mail Steamship Company, the pioneer fleet of the Pacific, came into San Francisco Bay, and this boat, the "California," was fol-

lowed by the "Oregon" a few months later. For 75 years, the flag of the Pacific Mail remained on the Seas. It was not only the pioneer among American ocean-going lines. It was also the pioneer in the establishment of a through Coast-to-Coast route.

FIRST TRANSCONTINENTAL ROAD.

The first transcontinental railroad was NOT the Union Pacific and Central Pacific through Ogden, nor any other of the lines that we nowadays hear so much about, but was a short line running across the Isthmus of Panama, and built and operated in connection with the Pacific Mail Steamship Company. It was chartered on April 7, 1849, and completed from Colon on the Atlantic to Panama on the Pacific in 1855. The Pacific Mail was doomed when the Panama Canal was created, and the Government in its wisdom decided that railroad-owned ships might not use that waterway in competition with the railroads. The railroad interest was finally sold and effort made to maintain the service through the Canal and by chartered ships on the trans-Pacific run, but this came too late, and the Pacific Mail flag disappeared from the Seas. Its activities have been succeeded to by the Dollar Line in the trans-Pacific service, and by the Panama Mail—a Grace line—in the Central and South American service.

San Francisco was in those days also the center of a very considerable inland fleet, using the waters of San Francisco Bay and the tributary rivers—Sacramento, and in lesser degree, the San Joaquin. Within four years after the discovery of gold, 23 steamers were operating on San Francisco Bay They did a lucrative business in connection with the mining regions to the east of Sacramento. Indeed at the time of the gold rush the vessels within the harbor were largely deserted. Full-rigged ships could not be sold at all. Smaller vessels, such as the barques, brought $5,000 and $10,000 each. The vessels that could be taken up the Sacramento River commanded as high as $20,000. It is related that boats would be taken up with mining supplies, beached, the crews taking the supplies and heading for the mines, giving no further thought for the vessels. These had to be towed at Government's expense into nearby sloughs and burned to prevent the obstruction of the navigable channels.

The other means of transportation in those days, aside from the muleback, were the slow-moving carretas of the Spaniards which had a solid buttonwood wheel with oxen as motive power, moving along at some two miles per hour. The prairie schooner was then created, a sturdy, strong vehicle piloted by two or four Missouri mules. These carried a good load and moved at a rapid rate. It is related that one outfit was sold in San Francisco for $1,140, and the purchaser charged his first customer just double that amount to haul two tons of freight from San Francisco to Sacramento, a distance of 90 miles.

EARLY FREIGHT CHARGES.

After the gold rush began the freight charges from San Francisco to Coloma increased from 10 cents a lb. to 75 cents a lb., or $1,500 per ton. It is probable that on the basis of mileage apportionment of earnings, the railroad haul for that same distance now yeilds about $1.50 per ton, or 1/1000 of the original charge.

One of the first established transportation enterprises was by Alexander H. Todd, of Stockton, who in July 1849 started a mail and express service between San Francisco and Stockton, using water of course, to Stockton, and vehicles into the interior. If you wished to become a customer you registered and paid $1 for that privilege. For each letter or parcel he delivered thereafter you were charged $4. He brought gold dust from the mines to San Francisco, charging 5 per cent. of its value for transportation. He was one of the first bankers and had a method which it might be well to consider the next time we have a stock market speculation under full swing. He charged the people for taking care of their money at the rate of 18 per cent. per annum.

STAGE COACH AND PONY EXPRESS.

The first transcontinental service by land was by the Army. The mail came via Panama until 1857, and in 1858 a regular overland mail service was established twice a week between San Francisco and Washington via Los Angeles and St. Louis, avoiding the impossible passes of the Sierra during the winter. The journey between San Francisco and St. Louis took 23 days. The Government subsidized this service at the rate

of $1,800,000 per annum. In the meantime, the Concord Stage had been created—a successor to the prairie schooner, and a very comfortable and dependable vehicle. A little later the pony express, said to make the remarkable time of 14 days between San Francisco and Washington via St. Jo, Missouri, had been established, the riders running at full speed in relays from station to station. This venture was not a success, costing the owners some $200,000, but in 1861 the first telegraph line was completed and the pony express went out of business.

THEODORE JUDAH AND THE "BIG FOUR."

There had been many dreams and many projects for a transcontinental railroad line after the early construction in the East. Speeches made in Congress were many and long, but it remained for a young engineer named Thedore Judah to convince Congress that a transcontinental railroad across the Sierra was a feasible and practicable thing. Satisfied that such construction would be authorized he came to California to get his project started and when Mr. Judah was introduced to Leland Stanford, a merchant in Sacramento, in 1860, the first transcontinental railroad was under way.

As fortune had it, there were in Sacramento four strong men of integrity, good standing commercially, of courage and of faith, who having set their hearts and minds to any task did not relinquish it. Their combined resources were probably less than 1 and one half million dollars. These men organized the first Central Pacific Railroad Company on June 28, 1861.

Leland Stanford had been a lawyer who, being burned out in his home State of Wisconsin, had moved to California and had gone successfully into the oil and grocery business in Sacramento. He talked the project over with his friend Collis P. Huntington, of the prosperous hardware firm of Huntington, Hopkins and Company, and they in turn discussed the subject with Mark Hopkins, Huntington's partner, and finally with Charles Crocker, dry goods merchant and contractor. They raised the necessary money for Judah to furnish his surveys, and then with maps and details Judah went back to Washington. There, the Congress of the United States which had already been pretty well convinced by Judah as to

both the practicability and desirability of his project, authorized the Central Pacific as a Company to undertake the construction from San Francisco eastward to the California state line, there to meet the Union Pacific building westward from Omaha. This was in 1862. There is not time this evening to go into the dramatic details of that period of construction from 1862 to May 10, 1869, when the Central Pacific at Promontory, north of Great Salt Lake, Utah, building eastward, met the Union Pacific building westward.

HOW ROAD WAS FINANCED.

These four men with limited capital but unlimited courage met with many obstacles. The Government granted the Central Pacific as a subsidy five odd numbered sections on each side of each mile constructed, requiring however, that a forty mile section be constructed before title was passed to the railroad for the land grant on each side of that forty miles. The land grant did not prove to be a very great help in building the road. As a matter of fact, nearly all the land was worthless without the railroad and a great deal of it is not worth very much even now, while taxes have added immeasureably to the investment without a corresponding increase in value.

The help the Government gave, however, in the way of 6 per cent. bonds was of very great value. This was at the rate of $16,000 per mile for the Valley lands in California, $48,000 per mile for the mountain sections over the Sierra, and $32,000 per mile for the sections across Nevada. The Government took a first mortgage bond upon the railway property for this help but because during the War period prices of construction went up two or three times Congress subsequently released its first mortgage lien and permitted the railroad, in order that the road might be completed, to substitute a first mortgage of its own for the purpose of raising other monies.

It is proper to say that the owners of the property found great difficulty in paying off the Government, and at one time it seemed that possibly they might have to relinquish ownership to the United States. However, they were eventually able to pay off the debt, and the mortgage was cancelled long ago.

PERSONALITIES OF BUILDERS.

These four men were extraordinary men in not only being individually of great capacity but because they fitted into an almost perfect partnership. The dominant figure financially, C. P. Huntington, said to a friend of mine some years ago "we were successful, we four, because of our team work. Each complemented the other in something the other lacked."

"There was Stanford, for instance," he said, "a man elected Senator and Governor, a man who loved to deal with people and who had a natural capacity both for understanding them and for getting himself understood. He was a good lawyer and in connection with our legal affairs and the franchises that were needed from the public, was very successful. Then there was Mark Hopkins. He was a fine accountant and understood the value of everything. He was a thrifty man, looked after our purchases and saw that we got a dollar's worth for every dollar spent. I have seen him personally go along the track," said C. P. Huntington, "and pick up spikes that were not in use and carry them to the section house and put them away."

"Then there was Crocker, the organizer, the executive, the driver of men. By his own efforts, his own power of leadership, he got the best out of men. They would work day and night for him. He set for them impossible jobs, and they did them. Crocker indeed had almost as many trials and troubles as those who were undertaking to raise the money."

It is related that he sent out 2,000 men from San Francisco to work on the railroad before he could get 100 to stay on the job, the rest going to the mines. He finally solved the problem by employing Chinese. He had at one time 25,000 at work. Some of these Chinese remained in the service of the railroad until very recently. They were strong, patient, enduring men, and supplemented the efforts of the Irish and other northern European laborers very successfully. It was largely as a result of Crocker's organizing power that the point of meeting with the Union Pacific was moved eastward three times.

There was great rivalry between the Union Pacific and Central Pacific as to laying of rail. The Union Pacific had laid six miles in one day and held the record. Crocker an-

nounced that he would lay ten miles in one day. It is stated that the Vice President of the Union Pacific wagered him $10,000 that it could not be done. Now laying rail meant distributing the ties, putting down the rail, bolting the rail together with angle bars, spiking it in place, then ballasting and surfacing the track so that it might be used. On April 28, 1869, with nothing but man power and little four wheel trucks, Crocker and his forces laid ten miles and two hundred feet of rail, losing one hour, as he explained it, in having to bend rail because they had to take a part of this construction around a curve. A train ran over it immediately at the rate of 30 miles an hour.

When Huntington was asked in narrating this story what part he played, he said "Well there were lots of little ways in which the others were too busy and not qualified to act where I could be useful." As a matter of fact, history deservedly gives him the most prominent part in the undertaking.

OTHER TRANSCONTINENTAL PROJECTS.

Before this line was completed the imagination of men had started other trans-continental projects. Tom Scott was engaged in efforts to build a line across the State of Texas to San Diego. The Southern Pacific railroad of California had been organized to build from San Francisco south to San Diego through Los Angeles and then eastward to a connection with the Atlantic and Pacific. This Atlantic and Pacific is a railroad that was subsequently built and is now a part of the Sante Fe System.

The Southern Pacific was incorporated in 1865, and by 1868 had acquired the railroad built from San Francisco to San Jose. They immediately began to extend southward to Gilroy, a distance of 30 miles, and about 80 from San Francisco. It was carried on down to a point called Tres Pinos, where it stopped, the main coast line diverging at Gilroy and going south through Watsonville and Salinas.

Before 1870, however, the Big Four, who had finished the Central Pacific, had acquired controlling interest in this as well as in other small local roads projected around San Francisco Bay, and eventually in 1901 this road was completed through San Luis Obispo and Santa Barbara to Los Angeles.

In the meantime they pushed south through the San Joaquin Valley, under the charter of the Central Pacific as far south as a point near Goshen, and then under the Southern Pacific charter had by 1874 reached the mountain wall that lies between northern and southern California, known as the Tehachapi. This is a rather abrupt mountain wall rising over 4,000 feet above the floor of the Valley at its lowest point.

SCALING THE TEHACHAPI.

Our then Chief Engineer, William Hood, told me of the various studies he made in an effort to scale this mountain, all unsuccessfully. Finally one night after he had gone to bed, thinking over this subject, a novel scheme came to his mind and the next day he rode his horse up through the mountains in the midst of a snow storm to see whether or no the was thinking along practical lines. He found that he was. The result is the famous Tehachapi Loop, involving some 18 short tunnels, the road on its ascent upward crossing its own trail.

In the centennial year the Southern Pacific had reached Los Angeles, and by 1881 had connected with the Santa Fe going westward at Deming, New Mexico, and in February 1883, the Big Four had completed another railroad, the Sunset Route, to the Gulf of Mexico. A few months later, the Northern Pacific had completed its line into Portland from the Twin Cities, and the Union Pacific had thrust its arm northwards from Wyoming also to Portland. In 1885 the Santa Fe line was finished from the east through to Southern California. The Great Northern reached Seattle in 1893. The Union Pacific was opened between Salt Lake and Los Angeles in 1905. The Milwaukee came west to Puget Sound in 1909, and in the same year the Western Pacific was finished between San Francisco and Salt Lake. There have been no new transcontinental lines built since that time. It is not probable there will be any new ones, at least for a long time to come. So much for the historical phase of railroad construction along the Pacific Coast.

GEOGRAPHY AND CLIMATE.

In considering transportation on the Pacific Coast we are confronted with geographical and climatic conditions that

are very different from those either in the east or central west. We have no great plains nor any great valleys, such as constitute the drainage of the Ohio, Missouri, and Mississippi Rivers.

We have the highest mountain ranges in the United States, the Rockies and Sierra Nevada and rivers intervening. Lying between the Rocky Mountains and Sierra Nevada we have a land of little rain, with great basins which at one time held great lakes and now have only their remnants. So little is the rainfall in this inter-mountain area that no streams flow out of the State of Nevada. But on the Coast side of the Sierra Nevada and Cascade ranges, and on the smaller Coast mountains near the ocean, there is a very plentiful rainfall for a major part of the distance between Puget Sound and San Diego, increasing as it goes northward, so the mountain walls and even the northern valleys west of the summit of the Sierra and of the Cascade have dense forests; California, Oregon and Washington possessing the remaining great timber resources of the United States.

In the north the Douglas fir, spruce and hemlock are on the western side of the Cascade, the pine forests principally on the eastern slopes. Southward in California along the Coast line is the great redwood belt; in the interior on the western slopes of the Sierra Nevada are the great pine forests.

It is a mountainous country, rich in minerals, rich in timber resources and rich agriculturally in the valleys where water is available. There are, it is true, two great valleys in California, the Sacramento and San Joaquin, or rather one which joins at the confluence of the San Joaquin and Sacramento Rivers, but on the whole California is a mountainous state and the valleys, especially those to the south, do not have a great rainfall. The crops are dependent upon irrigation.

The Pacific is a colder body of water than the Atlantic and gives up less moisture to the air. Our higher mountains on the Pacific catch this moisture as it is driven eastward and precipitate it into many torrential streams that have actual and potential water power of very great magnitude. The water that gives this power to wheels of industry, also irrigates the valleys below.

OIL AND MINERAL WEALTH.

We have no great coking coal deposits on the Pacific Coast. We have in Southern California one of the largest iron deposits in the United States but it has not been developed because of the lack of coking coal. We do have in central and southern California some of the largest oil fields in the United States, with the result that all of our railroad operations on the Pacific Coast use oil as a fuel. Our mild climatic conditions, and the richness of our soils make possible the production of crops with a very large yield per acre. This is indeed the salvation of our western railroads.

The demand for lumber is not increasing, and while our lumber resources are tremendous, we cannot make our eastern neighbors buy more than they wish. Our copper mines, especially in the territory lying east of the Sierra Nevada through Utah and Arizona, are productive and are of very great size, and we have also gold, lead and silver and many other metals that add more or less to our transportation resources. But as I shall point out later on, we are largely dependent on the growth of agriculture and on our trans-Pacific commerce to maintain our railroad systems in the west. Yet intensive agriculture takes up but a small part of our domain.

California has more than 150,000 square miles. In Government parks and reservations there are more than 34,000 square miles, i.e. more than 20 per cent. of the state. The land that is devoted to horticultural and agricultural cultivation under fence amounts to only about 10,200 square miles, or 7 per cent. of the State's area.

You may be interested in knowing the results of this intensive cultivation and its effect upon transportation. The lines on the Pacific Coast depend for one-third or more of their freight revenues upon perishable products. They handle a greater tonnage of grapes than they do of wheat. Lettuce and other winter vegetables provide a greater tonnage than wheat, corn, oats and barley combined. Products of the forest give about one-fifth of our total tonnage, and, of course, the products of the mines and road making materials with comparatively short hauls furnish the railroads with a heavy traffic, but with relatively small earnings. But largely they

depend upon the orange groves, lemon groves, vineyards, the great orchards of peaches, pears, plums, apricots and prunes and upon the great fields of lettuce, cauliflower, melons, artichokes and winter vegetables generally for the largest single item in their revenues.

FIFTEEN SUMMITS ON SOUTHERN PACIFIC LINES.

I have spoken of the mountain ranges on the Coast in connection with transportation. You will be interested in knowing that the main lines of the one railroad with which I am connected have fifteen summits west of Ogden, Utah, and El Paso, Texas, and south of Portland, Oregon, that range from 3,000 to 7,000 feet in elevation. We have 106 stretches of track more than one mile in length with more than one per cent. of grade, i.e., more than 52 feet to each mile. This is the situation today after 50 years of effort in reducing grades and curvature, by relocations, by building of tunnels, and the creation of fills.

The other Pacific Coast railroads have in this connection substantially the same problems as the Southern Pacific. This is of particular interest in view of the fact that these roads are so much dependent upon perishable traffic that must be moved expeditiously and on time for perhaps the maximum distance in the United States that commodities move to find their markets.

PANAMA CANAL COMPETITION.

The Panama Canal was opened in 1914. From that time on, a very large proportion of the heavy, non-perishable freight has moved by water between the Atlantic and Pacific Seaboards.

The railroads are not permitted to have any ownership in vessels operating through the Canal. They are not permitted to meet the rates that are made by water through the Canal unless they are willing to apply them to all intermediate points. There is a provision in the Interstate Commerce Act, commonly referred to as the Fourth Section, under which the Interstate Commerce Commission can, if it deems it wise, permit the railroads to meet such competition through the establishment of necessary rates without their application to intermediate points. So far the Commission has not seen fit

to grant this relief, but there has never been a definite decision on the subject. An important application of this nature is now before the Commission.

At this time articles of manufacture, especially those derived from steel, move from the eastern part of the United States as far west as Detroit and Chicago through either Atlantic or Gulf ports and thence by water to California, Oregon and Washington, and for some distance into the interior under rates that the railroads are unable to meet without making a sacrifice of intermediate revenues which they cannot afford. This situation is not economically sound. Of the steel and steel products moving trans-continentally not more than one-third move by rail.

Of the commodities, excluding lumber, moved from the Pacific Coast to the east that are non-perishable, such as beans, canned goods, raisins and the like, there is about an even division of the traffic between rail and water, notwithstanding that most of this traffic originates some distance from the seaboard in the interior of these Coast States.

HANDLING PERISHABLE FREIGHT.

Hence our dependence upon perishable traffic, and a wonderful traffic it has become. In 1929, 309,000 cars of perishable traffic moved from the Pacific Coast, not including the north Coast territory. You may be interested in knowing that the trains taking these oranges, lemons, lettuce, peaches and what not, move on schedules as exact and substantially as well maintained as those of passenger trains.

The concentration point in northern California where trains are made up for eastern movement is Roseville, a few miles east of Sacramento. Similar concentration points in southern California are Colton and San Bernardino, sixty miles east of Los Angeles. In the busy seasons of either vegetable or fruit production you will find activity in the fields until sundown. The last of the boxes are packed by artificial light. The closing hour may be 7 or 8 P.M., then waiting trains gather up these products, packed in refrigerator cars already iced or pre-cooled, as the case may be, and head them with special service to the concentration points I have named. There may be many or few cars in the train. That is dependent upon the crop movement and the season.

By agreement among the railroads and indeed by decree of the Interstate Commerce Commission, the schedules from Roseville in northern California and from Colton and San Bernardino in southern California to Chicago are the same. The agreed time now is 146 hours to cover some 2,200 miles of journey, but in addition, this agreed time is spread over a blanket area of country in both northern and southern California so that the 146 hours will apply from points 150 miles or more distant from a concentration point, more especially from Roseville, the contributing area being very much larger than from Colton or San Bernardino. This means that many trains must run from concentration point to Chicago in 130 hours. The railroads accept the responsibility of getting these trains through on time, if they do not do so, and loss arises from failing to make the day's market available under the schedule, the railroads assume the loss.

REAL RAILROADING.

This calls for real railroading, and the operating organizations of the railroad are keyed up to high pitch to give the effective transportation that is essential, so that the fruit gathered from the trees, or the vegetables taken from the field, may be placed upon your breakfast table here in the east in as fresh and acceptable condition as they were when they left their point of origin.

Problems arising are, of course, many: In lifting these perishable products over the two highest mountain ranges in the United States, through both cold and warm weather, getting them through on time and maintaining temperatures in the cars under all weather conditions that will best preserve them. The situation confronting us, however, from a railroad point of view, is woefully uneconomic.

First of all we have an unbalanced tonnage. The railroads send east from the Pacific Coast two tons for each ton they receive in return, principally because of the effect of the Panama Canal. Our country is also an unsettled country compared with that of the East. Two-thirds of all the population west of the Rocky Mountains lies within 150 miles of some Pacific Coast harbor. The great trunk systems of the east have from two and a half to three times the earnings per

mile that the Pacific Coast railroads have. The nature of our traffic, and the distance we have to traverse, make it necessary for us to maintain just as substantial and well built railroads as those in the East. The earnings of the Pennsylvania System run some $63,000 per mile, as against $21,000 per mile for the principal system on the Pacific Coast.

Of course we are a younger country, industrially and commercially generally. Our railroads in the East are not overburdened with tonnage. We are in the West even less so, and our crying need is for a round the year traffic that will keep our rails better occupied than at present.

We require in our perishable freight operations special equipment. The three principal California railroads own 58,000 refrigerator cars which, with ice plants and other facilities, represent an investment of some $200,000,000. At peak seasons of movements we borrow cars in addition from our neighbors.

HIGHWAY TRANSPORTATION.

Locally the Pacific Coast has become a country of good highways. We have the climatic conditions in the valleys that make for their use the year round. We have plenty of road making material immediately at hand. We have a population that is largely urban in nature, and resident, as I have noted, along the seaboard. Further, the purchasing power of the inhabitants of California is probably greater than that on the average of any other section of the United States. As a result, we have a local competition in the privately-owned auto, in the motor bus, and the motor truck, that is extensive and intensive.

Like the Panama Canal the good highway system of California has made for its progress. Without the Canal indeed we could not market our lumber and our oil as we have done, nor trade freely with many markets of the world, and without our good highway system we would not have the attractions for tourists and for homeseekers that we now have. The railroads on the Coast have found it necessary to go into the motor bus business and in the last year or two have engaged in it very extensively. During the last five years the electric railroads have supplemented their electric car service with motor buses.

PASSENGER TRAFFIC.

The effect of the motor vehicle upon passenger transportation has been much the same as elsewhere in the United States. The peak of our passenger transportation, both as to the number of passengers and revenue was in 1920. Since then it has declined about 30 per cent., though the year just closed has shown a slight increase over the year preceding. The railroads have lost the major part of their short haul traffic. They have retained their suburban and commutation traffic and their long hauls.

We find on the Pacific Coast, as elsewhere, that it is possible to fit ourselves to the new conditions. Our trains run faster with fewer stops. There is less obligation as a public necessity to take care of people at so many intermediate stations.

Twenty-five years ago the Governor of Oregon said to me that it cost more to bring the products of the farms to the railroad stations than it did to ship them from the railroad stations to the East, such was the condition of the roads. All that is now changed. Very often it makes little difference to the country resident whether he goes to one station or the other, there being good highways to both places. He can now with certainty accomplish in a few minutes what 20 years ago might have taken him hours with some uncertainty to do. As a result our trains need to make fewer stops. It is also true that with our climate on the Pacific Coast there is a less need for waiting room space, and less need for so many passenger stations. Yet the demand remains very strong for passenger stations that will be a credit to the cities they serve. It is indeed a problem to know how far we shall properly go as a matter of good will in meeting the desires of communities in building passenger stations that are ornate and impressive as well as useful.

There has been an urgent demand for some time in a certain large city in the Pacific Coast that we should join with the other railroads in the erection of a Union Station. An analysis indicates that if we were to put as much as $15,000,000 net into this new station, the interest return, the depreciation, and the maintenance charges above what we now have to bear, would wipe out all of the profit from all of our passenger

business west of El Paso and Ogden and south of Portland, i.e., that part of our Company known as our Pacific Lines.

In estimating this net revenue we use the basis laid down by the Interstate Commerce Commission for division between freight and passenger expenses.

GRADE SEPARATIONS.

The railroads of the West, where the population is increasing largely and in a somewhat narrow zone, have also to face the problem of grade separations, quite common throughout the country. To separate all of the grade crossings that present hazards in the State of California would require an increase in the money invested in the railroads of at least one-third. As an officer of our State Highway Commission remarked "It is not so much a question of safety as of delay that impels the demand for separation of crossings at grade."

Our traffic on the main highways is heavy. We are all alike when we are in our autos approaching the highway crossing, and have to wait while a 100-car freight train, a mile long, goes by.

TAXES.

And while I am on this subject of problems of railroads may I say a word about taxation which is common to all industry, all property owners, and all income earners all over the United States. Partly, of course, that problem has been accentuated by the great War. For anybody who earns anything, or has anything in a substantial way, the War was not over in 1918, and will not be over in our time or in our generation.

In 1885 the railroad with which I am associated paid $865,000 in taxes. Last year in connection with operating properties alone, it paid $21,525,000, a 25-fold increase. In that period our earnings increased ten-fold and our freight traffic measured by tonnage increased 18-fold. We pay in taxes, and I think this is true of many railroads in the United States, about the same amount that we pay out in dividends to our stockholders.

During this period since 1885 there has been, of course, a great advance in the art of railroading. The plants on the Pacific Coast, as elsewhere, are in every way more effective. The average locomotive load in 1885 was 157 tons. This had

risen last year to 556 tons. This reflects not only the increased power of the locomotive but the better road bed with its lesser curves and lesser grades, its heavier rail and greater ballast.

MAINTAINING THE ROADBED.

I presume you who are interested in engineering especially know a good deal about the exactness with which a railroad is nowadays made responsive to the demands upon it. The railroads in the United States are being constantly rebuilt. I remember the former Chairman of our Board, Mr. Julius Kruttschnitt, saying some years ago that in his time the Central Pacific, i.e. our line between Ogden and San Francisco, had been rebuilt three times. Rail, for example, under heavy use may last only three or four years on the sharper curves, and on tangent lines it may be good for twenty years or more. Ties, of course, are perishable. Ballast is fouled and has to be renewed, and all structures have to be made responsive to the heavier power that we put upon them.

The 50 and 60 pound section rail has given way within my time on main lines to rail weighing from 110 pounds to 130 pounds to the yard. In ballasting a new line or reballasting an old, in laying rail on a new line or in relaying it on old, a chart is made by the engineers showing the traffic that has flowed over the old line or that is anticipated over the new line, and this is projected forward for a period of years. Curvature and grades, especially curvature, are then taken into account, and ballast and weight of rail definitely determined from these tonnage figures and charted accordingly. Speed is also, of course, an element to be considered. So nowadays in the purchase of the locomotives the duty of the locomotive at this time and its prospective duty, and its availability for joint use, freight and passenger, since we have come into the period of high speed for both, is measured, and the locomotives are designed to meet the physical conditions on the one hand that they have to overcome and the needs of the traffic that they have to move on the other.

TRANSPORTATING AGENCIES.

The railroads of the Coast regard themselves as transportation agencies in general. They connect with steamship lines,

in some instances they operate water craft locally. They have gone into the motor bus business, and they are experimenting with the motor truck as an auxiliary to rail service. They are keeping a close eye on service given by air, and have established in some instances a joint service therewith. They are, of course, the great agencies for an efficient public transportation.

Perhaps I may be pardoned in using the railroad with which I am associated so frequently as an illustration, but I know it better than I do any other. Our gross earnings in 1928 were some $300,000,000. Earnings from outside sources, auxiliary operations of electric lines and other investments, amounted to about $34,000,000. Out of this $334,000,000 some $22,500,000, or less than 7 per cent., went into dividends to our stockholders. About the same amount went in interest to people who had loaned us money. All the other money that we received, and more, went back to the public for the operation of the road, and the extensions, additions and betterments that were found necessary in the public interest. That is to say on one hand we took in a dollar from the public, gave it transportation, retained less than 7 cents for our stockholders and immediately passed the balance out for distribution to the people along our lines for services rendered, for materials and for taxes.

We have now another very interesting problem before us, viz.: The suggestion that the railroads of the United States shall be consolidated into 19 large systems. The Interstate Commerce Commission following the mandate of Congress has gotten out a plan accordingly. I am not going to discuss that tonight, except simply to say that as a rule railroads and communities have grown up together. In leaving intact these major systems in their suggestion the Interstate Commerce Commission has shown wise judgment. They have been given an impossible task, and they have met it, of course, as best they could. It need not be discussed tonight. I think you will have it with you for a long time to come.

Finally, may I say in closing, that the managements of the Western railroads do not fear the future. They have nothing to ask except that under the law they be given equality of treatment and equality of opportunity along with our inland

and outside waterways and our highways, and any other form of transportation facility that may be created in competition with them.

The great asset of the Pacific Coast railroads is the rapidity of the growth, the desire of people to come to the Pacific Coast to live, and the magnitude of the resources available for human consumption elsewhere, even though at present there be no unfilled demand.

I hope that all of you at some time before long will have opportunity to go out to visit us at the Coast, to ride on our railroads, and get acquainted with our country.

SPRAYED MOLTEN METAL COATING PROCESS AND RESULTS.*

BY

RICHARD L. BINDER,

President, Metals Coating Co. of America, Philadelphia,
Member of the Institute.

It has seemed to me that the first thought which connects itself with The Franklin Institute is Progress, either that of the past or that in the making. Naturally the branches which come to mind are inventions and usually deal with mechanical developments. When we look upon the many conveniences, now accepted as commonplace necessities which, since time began, were first brought to public notice in this hall, there attaches to the Institute a reverence which is almost beyond conception.

My subject tonight deals more with the development of an invention than the invention itself. I am frequently asked how MetaLayeR was conceived and then my mind wanders back to a scene, undoubtedly more poetic than practical, but nevertheless interesting, in which is portrayed a band of savages—primitive men grouped near a fire around which stones have been piled. They are cooking their simple meal. The more hungry ones take first choice of the food. Eventually all are satisfied and the smoldering embers are scattered. Their curiosity is aroused by small nodules which appear mixed in with the ashes. These particles are unusually hard, different in appearance from anything they have before seen. When pounded they flatten out without fracture and have properties or qualities which even the undeveloped mind of the savage recognizes as being useful. Thus probably was the first metal smelted and from that time its manufacture and applications have grown into the endless list of materials with which we are now familiar.

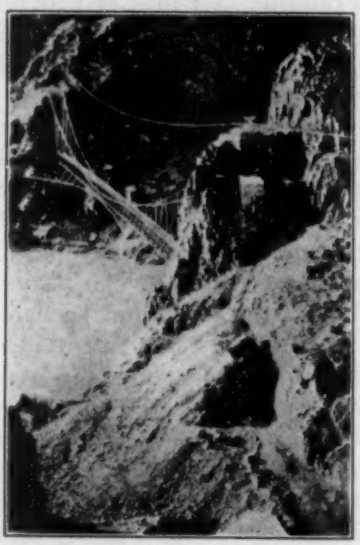
With metal available, the only limit to its usefulness was the ingenuity displayed in its application. Practically every

* Presented at a meeting held Thursday, February 27, 1930.

demand has been met with a solution. The first step dealt with its founding and from then on through its alloying, rolling, heat treating, machining, etc., it has seemed that no limits of its adaptability could be reached.

In each branch of metal working what at first seemed fundamental operations promptly brought about variations of procedure. For instance, the foundry at the start involved only a method of melting and pouring metal into a simple mould. Eventually the use of cores was developed and then

FIG. 1.



permanent moulds, die casting, centrifugal casting, etc., followed.

About fifteen years ago some vague ideas of an inventor so shaped themselves as to permit of the construction of a device which would allow metal being used in a manner entirely different from that which was previously possible. The revolutionary character of the invention immediately attracted the attention of technicians in industry and as a result it was hailed as being a universal panacea for all industrial ills.

The result was that before the mechanical details of construction were properly solved, the natural optimism and enthusiasm of progressive business managers caused them to adopt it. Encountering difficulties such as are usually met with in complicated mechanisms, they became discouraged and their interest in the invention was allowed to wane.

The development of an invention may be likened to a condition which existed between the two towns, Kaibab Forest and Grand Canyon in Arizona. These towns are only eleven miles apart; but mail going between the two, formerly traveled 1025 miles, through four states, before it was delivered. The Grand Canyon of the Colorado lay between them.

Kaibab Bridge now spans the gap and a matter of half an hour serves to complete the journey.

Without going into too much detail, I will endeavor to hold your interest in an account of my experiences in taking hold of the incomplete invention referred to and in "bridging the gap" between its original lack of suitability and its present successful and useful place in industry.

It is entirely proper to describe MetaLayeR and our Sprayed Molten Metal Coating Process as being actually a modification of foundry practice.

Having now referred to MetaLayeR and the Sprayed Molten Metal Coating Process, it will probably save time and more clearly describe just what these are by showing MetaLayeR in operation.

You undoubtedly are familiar with the usual foundry practice wherein the cupola is charged with metal which, as it melts, is drawn and poured into moulds. Actually we do practically the same thing with MetaLayeR, but in a somewhat different manner. Instead of taking raw material in the form of ore or pig or scrap, we use metal in the form of

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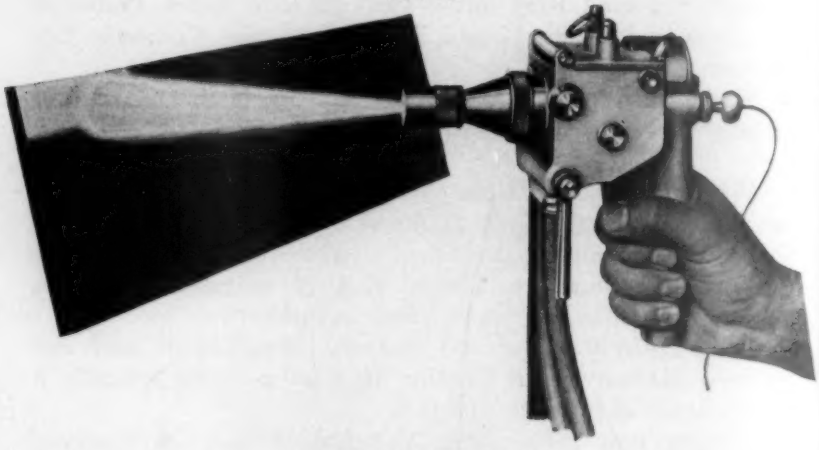
Editor's Note.—MetaLayeR was demonstrated, spraying iron, zinc, aluminum and tantalum. Zinc was also applied to the interior of a 1" iron pipe, using the recently developed rotating nozzle attachment.

The lecturer stated that MetaLayeR provided the only commercial method of applying aluminum and that this was the first time that tantalum (melting temperature 5162° Fahr.) had been sprayed in public.

wire. It automatically feeds through MetaLayeR into an oxy-acetylene flame, which melts it, and we then use compressed air to carry, or practically to pour, the molten metal in minute particles onto a surface. We are thus undoubtedly carrying out regular foundry practice; but by a method which gives a unique control of results, and with this control we are able to meet requirements of enormous economic importance and to satisfy demands which have existed ever since property began to accumulate.

FIG. 2.



MetaLayeR in operation.

One of the basic laws of nature is that material, if left to itself, tends to deteriorate. Since time began, means to combat this law have been our first concern.

Originally, man had available for his needs stone, wood, some metals, and plant and animal life, all in their natural basic condition. The transformation of these raw materials into what are now recognized as life's necessities not only required ingenuity but also called for the expenditure of time and labor.

As civilization advanced, the value of labor increased and the necessity for the prevention of the deterioration of the raw material on which labor had been applied, manifested itself.

Property, representing the labor expended on the raw material, accumulated and an inherent desire was created to

preserve it, and this desire was cumulative as the values of the property increased.

With the desire to preserve came also the desire to improve and the ability to combine methods for preventing deterioration with those for beautification, was a most important step in the advance of civilization. Were we to discontinue the use of methods for preserving the values of our labor represented in our properties, these properties would undoubtedly return to their original condition and man would revert to his primitive manner of living. It is therefore reasonable to measure the advance of civilization by our capacity to *Build for Permanence.*

From the first efforts of the savage to protect his modest hut or even his person by smearing them with mud, on through the uses of vegetable gums, paints, glazes and other methods with which you are familiar, up to the perfection of MetaLayeR and the development of our process, an almost inconceivable amount of effort and experiment have been expended.

Since MetaLayeR was made commercially available, Sprayed Molten Metal Coatings have been successfully used as a protection against atmospheric corrosion or chemical action, or from deterioration due to exposure to high temperatures, or for replacing mechanical wear, or for increasing dimension or weight, for altering shapes and repairing defects in surfaces, or for developing decorative effects. Coatings of different metals, regardless of their melting temperatures, successively applied, may be readily developed.

Briefly, any commercial metal can be applied to any other commercial metal, and any commercial metal can also be applied to any base or surface, such as wood, plaster, stone, leather, glass, porcelain, concrete, paper, fabrics, etc. The coatings as applied are instantly cold, hard, dry, ready for use. They will serve for any purpose for which a sheet metal covering is adapted.

An important feature of MetaLayeR is that it is applicable for use in conjunction with any of the other methods of applying coatings and should not, therefore, be considered as competing with them. While MetaLayeR has a field of its own in mechanical work for which none of the other methods can be successfully used, yet it may be advantageously

adopted as an adjunct for production by the Autogenous or Electric Welder, the Electro-plater, the Hot Dip Galvanizer, the Sherardizer, the Painter, the Decorator or the Enameler.

FIG. 3.

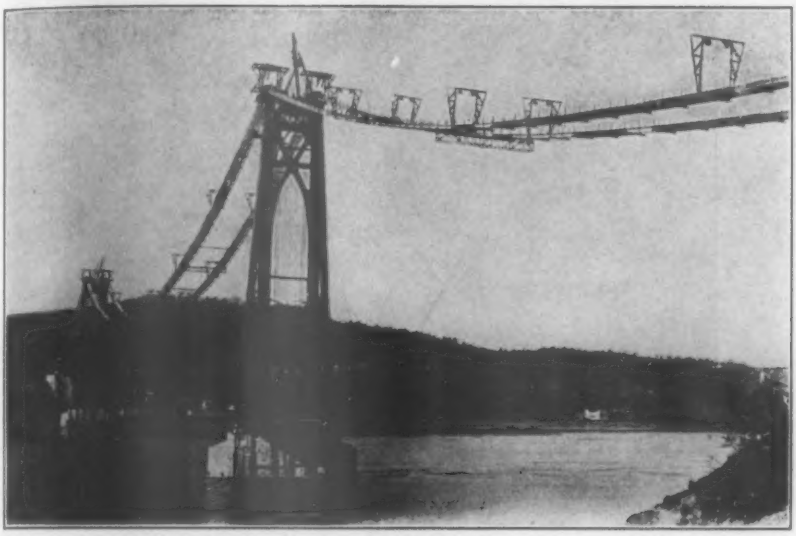
Spraying molten nickel to increase diameter of driven shafts on speed reduction gears to secure proper fit for ball bearing race.

It is necessary to differentiate between our coatings and those deposited by other methods. We use no pigments, vehicles, solvents, fluxes, etc. Into MetaLayeR is automatically fed commercial metallic wire. It melts, it is atomized, is impacted, instantly cooled and is transformed from the wire into a sheet metal covering upon the surface being treated.

Sprayed metal coatings applied with MetaLayeR may be turned, ground, filed, milled, shaped or polished. They become practically an integral part of the surface on which they are placed.

The use of MetaLayeR is not restricted to the shop. It has been operated on lofty towers; on ships at sea; on moving railroad trains; on bridges; railway stations; inside and outside of tanks and conduits; on hydraulic and steam turbines as installed; on rams; crankshafts; calender rolls, etc. Any reasonably intelligent mechanic can operate it.

FIG. 4.

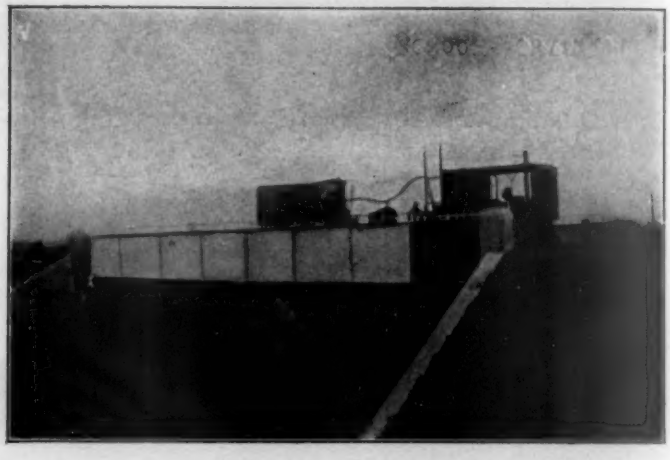


Connectors for wires forming cables for Hudson River Bridge are coated with sprayed molten zinc.

FIG. 5.

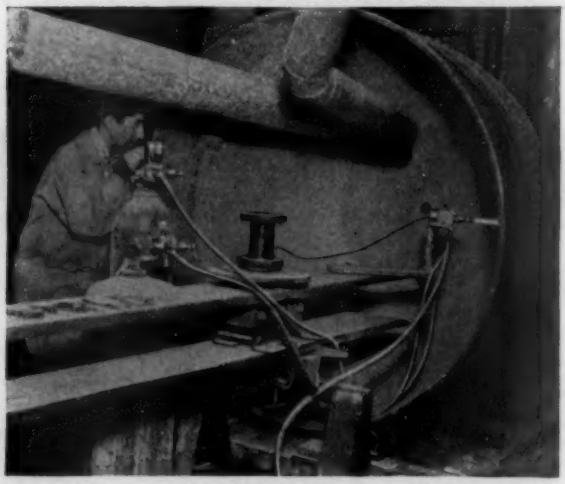
Superheater tubes and supports and other furnace parts exposed to high temperatures on S. S. "Bremen" and "Europa" are alumetized.

FIG. 6.



Bridge girders coated with zinc, lead or aluminum.

FIG. 7.



This 500-gallon tomato cooking kettle 5′4″ dia. by 6′ deep is having 450 sq. ft. coated with 1/32″ of tin.

Coherent attached or separable metal coatings in molten form are applied to any reasonable thickness desired, on all or *any* part of *any* material—whether inflammable, vitreous,

fibrous, metallic, conducting or insulating. Work may be done with it either in the shop or in the field and either before, during or after fabrication.

FIG. 8.

Crank shaft accurately balanced by application of sprayed molten steel.

FIG. 9.

MetaLayeR was used to overcome porosity of a large hydraulic-press plunger. A 3/32-in. copper coating cured the trouble and prolonged the life of packings.

To indicate the broad field and the purpose and scope for which sprayed molten metal coatings are suited, it was my intention to list the important work for which they had, in a practical commercial and economic manner, been used.

However, a partial completion of this list made me realize that much more than the time available would be needed, and the attention required to read it intelligently would be prohibitive. Such a list would practically constitute a complete directory of industry, starting with Abbatoirs and going through Aëroplanes, Architecture, Art Workers, Automobiles,

FIG. 10.

Two calender rolls, costing $3,000 each, had journals 0.01 in. under size. They were salvaged by being sprayed with nickel and reground. Cost, $164 for the two.

Boiler Makers, Bolts, Breweries, Builders and Contractors, Burial Caskets, Chemical Apparatus, Dairy Equipment, Electrical Manufacturers, Gas and Electric Fixtures, Foundries, Machine Shops, Municipal Engineering, Nail Manufacturers, Paint Makers, Plumbers' Supplies, Railroads (Steam and Electric), Ranges, Refineries, Ship Builders, Structural Steel Constructors, Tanks, Ventilators, Welders and so on through the many intermediate industries to the very end of the alphabet.

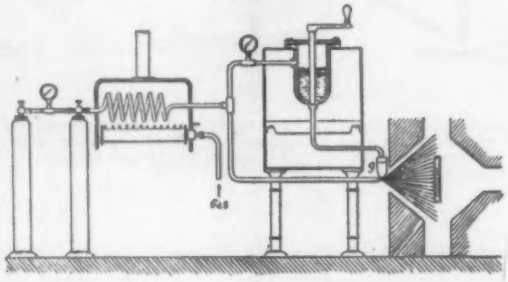
In short, anything which can be painted will be better if metal-coated, and many things which cannot be covered in any other way may be easily cared for by MetaLayeR.

Some of the metals which can be applied by MetaLayeR are: Zinc, aluminum, lead, tin, copper, bronze, cadmium, brass, German silver, nickel, nichrome, monel, iron, stainless steel, gold, silver, phosphor bronze, aluminum bronze, eutectic alloys, bismuth, selenium, manganese and tatalum.

Having described the process, I believe you will be interested in following through some of the steps required to develop MetaLayeR and to perfect it.

Consideration was given to practically every known method for melting metal in a manner which would permit of using it for the purposes desired. This diagram shows the first molten metal spraying plant with which coatings were developed.

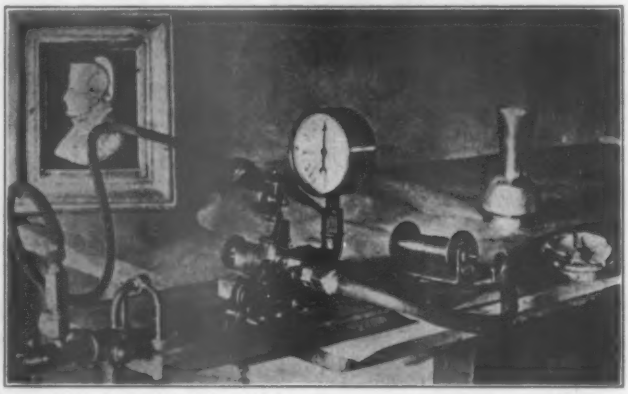
FIG. 11.



The first molten metal-spraying plant suitable for commercial practice.

The difficulty encountered in this type due to the metal freezing (solidifying) in the discharge tubes quickly led to its abandonment.

FIG. 12.

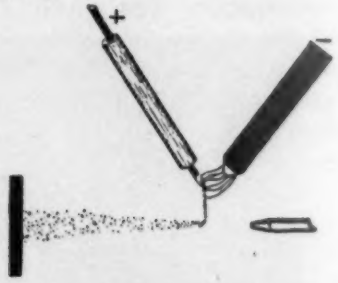


Eventually this apparatus was constructed. It contains all the essential principles of successful operation but lacked suitable means for adjustment and control and also lacked portability.

Some idea of the scope of experiments may be gained from the following diagrams.

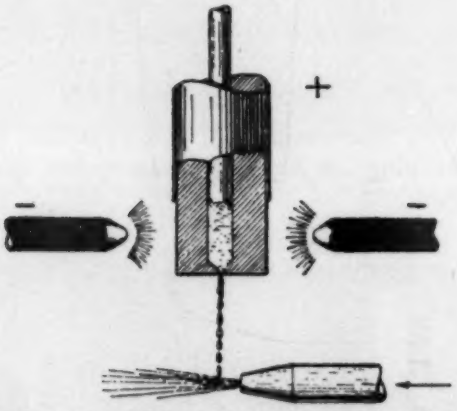
FIG. 13.

Diagrammatic representation of experiment to determine whether wire could be melted and sprayed.



Diagrammatic representation of experiment to determine whether wire could be melted electrically and sprayed.

FIG. 14.

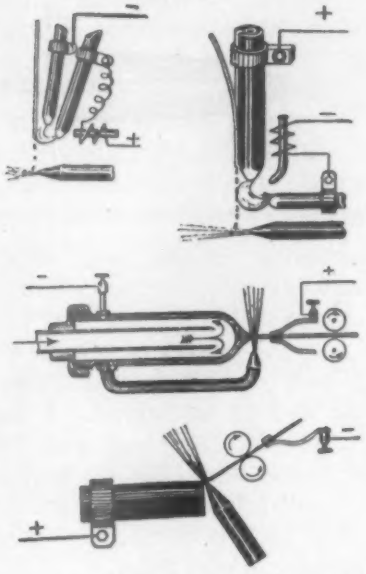


Improved experimental design for electrical wire melting and spraying.

They represent various methods for providing melting mediums: electric current, illuminating gas, hydrogen, and oxygen, and eventually Acetylene and Oxygen.

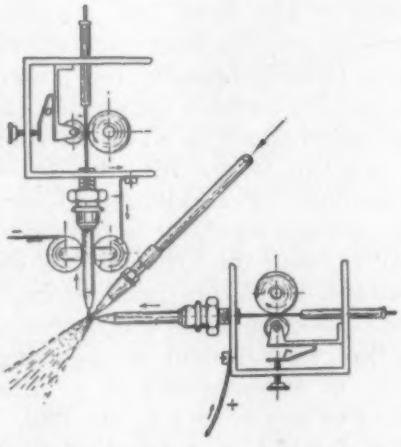
At this time my personal connection with the development took place. What seemed like endless calculations and

FIG. 15.



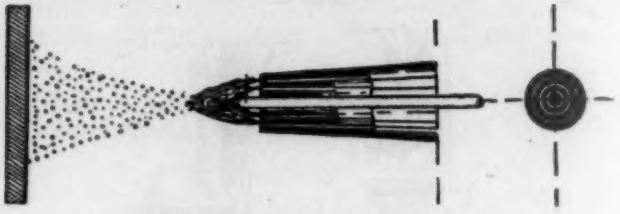
Further possible methods of using electricity in metal spraying.

FIG. 16.



Diagrammatic view of the apparatus shown in Fig. 15.

FIG. 17.



Improved experimental design for wire spraying.

experiments eventually enabled me, after three years of intensive and *expensive* research, to determine just what we were trying to accomplish. Up to that time I feel certain that my efforts and the efforts of others who were working in the same field, were expended without any clear knowledge of what problems had to be solved. I am of the opinion that we had been working too much with our hands and not enough with our heads and that we had been placing too much dependence and reliance on the inventor, who himself did not know what had to be accomplished to provide dependable and commercial operation.

A very important step in the advance of the industry was my realization that what was needed was a power plant, preferably operated by compressed air, so controlled that it would feed metal in wire form, into a melting furnace at a rate which would absorb the heat units therein, and a means of maintaining a balance between the power plant and the capacity of the melting furnace, throughout the varying range of the melting temperatures of all of the commercial metals.

With this problem before me, the development of the power plant operated by a compressed air driven turbine controlled by a pressure regulator in combination with needle valve and the control of the furnace—i.e., the oxy-acetylene flame—with suitable regulators, resolved itself into comparatively simple mechanical motions which were readily provided; the result was that we soon had an operating piece of apparatus, equivalent in dependability to a lathe, a drill press, a planer, a shaper or any other machine tool. The simplicity with which this control is maintained is what impresses observers as being the most remarkable principle of the process.

MetaLayeR in operation is connected to a supply of acetylene and oxygen gas, and to a supply of compressed air. While in actual use, it consumes about 15 cubic feet of each of the gases per hour, and 50 cubic feet (at 50 lbs. per square inch pressure) of compressed air per minute.

Metal in the form of standard gauge wire is automatically pulled from a reel by the feed rolls in the gear case, and is passed uniformly and continuously, at the rate of from 12 to 24 feet per minute, to the nozzle of the short barrel.

From the nozzle the wire enters into a continuous reducing flame zone, developed with the gases, and is there melted, atomized and blown in a very fine molten spray, onto the surface to be coated.

The spray of molten metal thrown by MetaLayeR covers, on a surface five inches from the nozzle, a circle approximately two inches in diameter. Objects to be sprayed with metal are operated upon by pointing MetaLayeR normally at the surface to be coated, about four inches distance therefrom. In this short distance takes place the change of the wire from its solid to a molten state, thence to the spray, and instantly back to the solid, practically cold coating. The temperature of the surface being coated is raised but slightly, and it is possible to apply coatings to the most delicate objects. As an evidence of the perfect control of the spraying operation, the thinnest paper, fabrics and wood receive the impacting particles of the molten metal without charring.

MetaLayeR is traversed across the surface with a regular motion. A single pass develops a coating about 0.001″ thick. The operator's vision easily guides him in distinguishing between the coated and uncoated portions and also between a first and second coat.

For building up dimensions or filling defects in surfaces, coatings of any desired thickness may be applied. In practice this thickness is easily regulated. Four to ten one-thousandths of an inch (0.004″ to 0.010″) well impacted upon a surface, is for many kinds of work just as effective as a much greater thickness, and, of course, unnecessarily sprayed metal increases the cost of production.

With the advent of the successful MetaLayeR it might reasonably be expected that the reward in the way of profitable business was at our command.

My first experience in attempting to exploit its adoption and use by industry was to be met with definite skepticism, amounting in many cases to ridicule, of my claims that such radical methods of using metals would produce commercial results. The statement of John Stuart Mill that "Every great movement must experience three stages—Ridicule, Discussion, Adoption," was forcibly impressed on me.

I quickly realized that, in addition to having at my command a fairly complete knowledge of mechanics, I would also be required to solve problems in electrical engineering, civil engineering, metallurgy, chemistry with all of its ramifications, taking in oil refining problems, sugar refining, dairy industries; lumber, building construction, designing and decorating, sewage disposal, etc., and in each one of these in order to secure business I was expected to accomplish results and solve problems which had never been satisfactorily cared for.

I had to prove that I could do so before being permitted to proceed, and also before securing permission, I had to convince prospective customers that costs of performance by our process would be warranted by results attained.

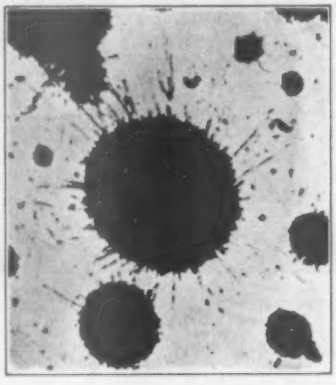
One of the great obstacles to progress is the inherent unwillingness of ordinary business executives to change their point of view—the lazy-minded assumption that anything differing from established practice must be unworthy of attention. It is fortunate for mankind that the closed-mindedness of the commercially trained man does not extend to the scientific world. If it did, we would still be riding in horse-drawn buggies, and when we look aloft would see only gnats and birds and clouds, instead of aëroplanes and dirigibles.

This condition made it necessary that the principles of MetaLayeR and our Sprayed Molten Metal Coating Process should be set forth in a manner easily within the grasp of the lay mind, and deep thought and much care in the manner of presenting them was required.

The best description I have ever heard of a polished surface is that it is "a multiplicity of scratches." Analyzing sprayed molten metal coatings develops that they are made up of a multiplicity of plastic particles which, by impact on

a surface are flattened out and interlocked, first with the microscopic open grain on which they are deposited, and subsequently with each other.

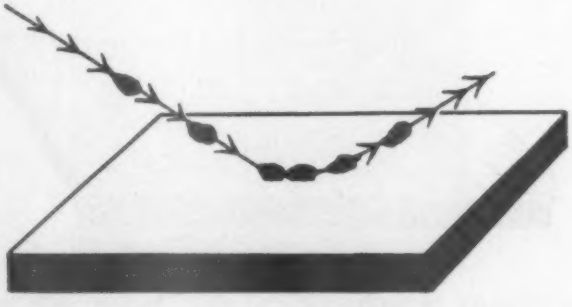
FIG. 18.



Atomized particles of sprayed molten copper after impact, × 50 diameters.

The mechanism of and correct conditions for their adhesion may be explained as follows: If a moving metal particle, which is surrounded by a certain amount of air, strikes, in a heated condition, upon a smooth plate, it makes a sliding movement before coming to rest.

FIG. 19.



Shows how a metal particle may strike and glide along and glance off a smooth surface.

As this requires a certain amount of time, the particle will cool. Air contacts with it and further reduces its tempera-

ture. The particle will then, following its gliding movement, rise from the surface again and describe a path as indicated in the above illustration.

A continual following bombardment of metal particles will hence develop a coating as shown in the illustration below and thus no firm bond will be secured.

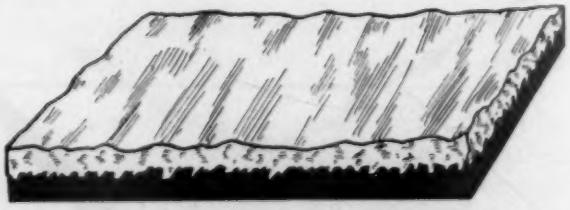
FIG. 20.

Showing in diagram deposit produced by attempting to coat a smooth surface.

The coating contacts with the surface only at intervals and inferior adhesion results.

If now the surface is roughened, preferably by sand blasting, and sharp elevations and depressions are produced, a train of heated metal particles (actually melted in our process) projected against it, immediately come to rest—no sliding taking place, and they individually instantly key or dovetail to an extent in proportion to the temperature of the particles and the speed with which they strike.

FIG. 21.



Deposit on a roughened (sand blasted) surface.

Thus a spray of molten metal particles on to a roughened or open grained surface immediately comes to rest on striking and firmly anchor themselves to the foundation and develop a bond which is as strong as either the metal applied or the material to which it attaches.

The microphotographs clearly indicate what results are secured in practice.

FIG. 22.

Coating of sprayed molten metal on sand blasted steel surface. × 100 diameters.

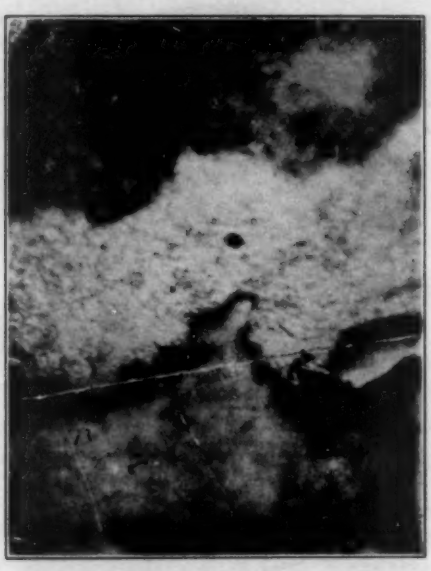
FIG. 23.

Section of steel, showing dovetailing and interlocking to roughened, open grained surfaces, developed by sand blasting. × 60 diameters.

By an astonishingly simple method, detachable coatings are produced, in contradistinction to the permanently adherent coatings. A surface is so prepared that the sprayed

molten metal applied in the usual manner builds up to the

FIG. 24.



Another section, × 600 diameters, indicating intimate mechanical bond secured.

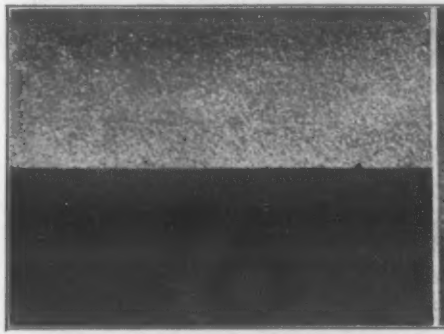
FIG. 25.

Sprayed coatings are intact after shell had passed through target.

required thickness. It may then be lifted off, and will be found to have followed the physical contour of the original with unfailing accuracy of detail. The positive may be used repeatedly without injury. By the same methods the reproduction may be also copied in reverse.

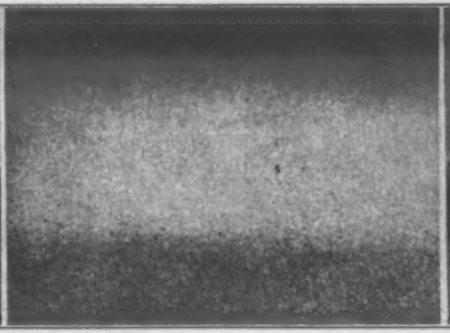
Frequently the question is raised as to how strongly MetaLayeR coatings will adhere to a surface. Fig. 25

FIG. 26.



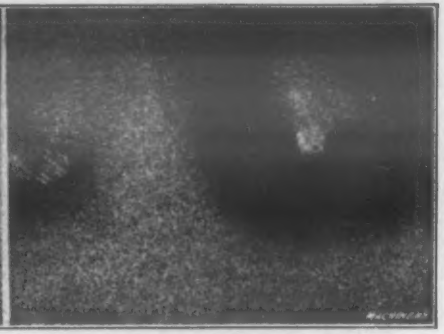
A surface sprayed with copper, the top half showing natural finish of the sprayed surface, the lower half showing the coating has been polished.

FIG. 27.



Brass coating at top blended into aluminum at the center and copper below. This is the only process by which such results can be secured.

FIG. 28.



Shows how metal may be piled on by holding the tool at one spot. Note top of one pile has been filed, indicating solid character of the deposited metal.

SHOWING AS NEARLY AS POSSIBLE WITH A BLACK AND WHITE ILLUSTRATION WHAT THE COATINGS LOOK LIKE.

provides the answer. Thousands of shells were coated by MetaLayeR with zinc, copper and lead to correct imperfections in dimension weight, or balance. Many of them showed, as does this, that even after the terrific ordeal of firing and passing through the target, the coatings were intact.

To completely commercialize the process, it became necessary to provide means for reaching all kinds of surfaces as well as all kinds of materials. Areas difficult of access are coated with special types of nozzles attached to standard MetaLayeRs. For example, with the rotating nozzle the interiors of castings, pipes, cylinders or vessels having small orifices can be coated with sprayed molten metal. Coatings can be applied to the inside of a pipe as small as one inch in diameter, up to twenty feet in length. This application of MetaLayeR has great economic importance. It is the only method for the commercial lining of pipes with practically any metal. In Figs. 51 and 56 is seen an operator using the rotating nozzle.

MASS COATING MACHINE TREATS SMALL PARTS IN BULK.

Pieces weighing anywhere from a fraction of an ounce up to approximately one pound are placed in the specially constructed rumbling barrel in lots of about one hundred pounds at a time. Sprayed molten metal from MetaLayeR is directed on them as they rotate and the coatings are evenly deposited on the surfaces of the entire lot, in one operation. Threaded parts do not require re-threading, nor is the temper of hardened pieces affected in any way. Objects are entirely covered by the coating and, if desired, may be ball polished or rumbled in leather scrap before removal. Cost of operation, rate of output and quality of product compare favorably with any other method for the metal coating of small parts.

While the sprayed molten metal coating process was originally conceived as a method for protecting iron and steel from atmospheric corrosion, requirements of industry have broadened its field of application to a practically unlimited extent. As much, or in fact more, research was required to determine what channels provided outlets for the commercial results obtainable from its use as was needed to perfect the

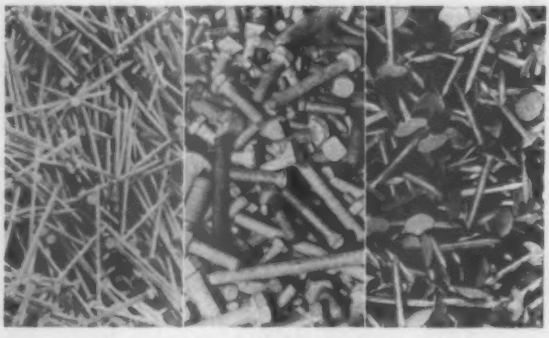
mechanism. Some applications, entirely practical from a technical and mechanical point of view, did not properly come within its purpose and scope, either because they could

FIG. 29.

Mass Coating Machine used for spraying small parts in bulk.

be done better by other methods, or due to the result aimed for not being worth the effort.

FIG. 30.



Showing some of the materials which are zinc coated in Mass Coating Machine.

On the other hand, MetaLayeR and the results obtainable by its use have brought deserved recognition from production and maintenance engineers. They have become important factors in many industries, and manufacturers and users of all kinds of equipment are realizing, and rapidly taking

advantage of, its wonderful possibilities, knowing that they now have at hand most dependable and versatile methods of getting benefits from the use of metals which were not heretofore available.

Many products of industry, possessing certain inherent properties which should fit them for specific purposes, often fail in service for a slight lack of some very desirable quality. As a rule, their failure is first evidenced on their surface, and therefore improving the surface frequently brings about the desired result. MetaLayeR's function is largely to "improve the surface," permanently, by developing thereon coatings of sprayed molten metal and to practically secure on any surface at very low cost the desirable qualities of the more expensive metals, and to use the cheaper and the usually stronger material for the bulk or mass of the product.

PROTECTION WITH ZINC.

For the protection of iron and steel from atmospheric corrosion, zinc coatings admittedly take the front rank. Zinc is the most electro-positive metal which can be practically used for coating iron and steel, and from this point of view it is better suited for the purpose of providing an inhibitive coating than any other metal. On the other hand, on the basis of the electrolytic theory of corrosion, the solution tension of zinc is high and its power of protecting iron is accomplished mainly at the expense of its own destruction. For this reason, zinc must be considered, at the very best, as an inhibitor rather than a prohibitor of corrosion and in use a time must inevitably arrive when even the best of zinc coatings will fail.

In considering the subject of protection, it must be accepted that porosity in metals is a relative term, and that no metallic element is entirely nonporous and, therefore, the dependence which has previously been placed on coatings, due to their supposed freedom from pores, has actually been without practical foundation.

With the sprayed molten metal coating process of protection, it is admitted that there is a relative porosity of the coatings; but this porosity may be modified by various methods of applying the coating or by different treatments

of the surface after the coatings are placed. Actual service tests have shown that this porosity, in the case of zinc coatings, favors the rapid formation, throughout the thickness of the deposited zinc, of either hydrocarbonate or oxychloride of zinc, which tend to seal up the pores and which are the best known protecting media for Iron and steel. The development of these compounds also reduces the electric potential stress between the iron or steel and the zinc coating and, while affording absolute protection of the base, also retards the destruction of the zinc.

With the sprayed molten metal coating process the objectionable features of subjecting the iron or steel surfaces to the action of the dipping acids or fluxes are eliminated and the purity of the zinc, as applied, is maintained. There is no formation of alloys which will affect the corrosion resistance inherent to the pure zinc.

Most metals corrode or oxidize progressively; but zinc, aluminum and lead do not, and herein lies their protective value. Iron and zinc are both attacked by moist air containing carbon dioxide, sulfur dioxide, salt, etc., but while iron forms a loose incoherent mass of rust, through which more moisture and air readily find a way and cause corrosion to proceed unchecked, it is different with zinc. On the latter a layer of salts is formed—zinc oxide and carbonates. This is tough and adherent and forms a protective surface which prevents the entrance of air and brings the corrosive action to a standstill. Should a defect in a surface coated by the sprayed molten metal coating process develop, a repeated application may readily be made to the local defect. By no other method is this commercially practical.

To determine the comparative protection of Sprayed Molten Metal Coatings, as applied by MetaLayeR, with two methods of painting, a section, measuring 12″ x 34″, of a sand blasted steel sheet was first coated with sprayed molten aluminum 0.004″ thick, and then covered with sprayed molten zinc 0.004″ thick.

On a section 12″ x 17″ a first coat of red lead paint was applied, then a second coat of (Goheen) carbonizing paint, and then a third coat of (Goheen) carbonizing paint were applied. On an adjacent section, also 12″ x 17″, a first coat

of red lead paint, then a second coat of standard No. 4 paint, and then a third coat of standard No. 6 paint were applied.

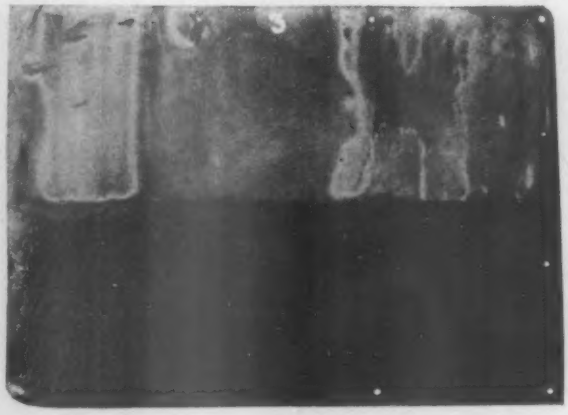
FIG. 31.

The illustration, made after forty-six months' exposure to the direct fumes passing through ventilator in roof of the Reading Railroad train shed, shows that the steel covered with sprayed molten metal has not rusted, and no pitting is present.

The painted sections are badly blistered and deep pitting of the iron has taken place under each blister. In some places the pits are very nearly through the entire thickness of the sheet.

The other side of this same sheet, which faced away from the ventilator, but around which the gaseous fumes freely circulated, shows that a decided protective value of the sprayed metal coatings still remains. No pitting is present on the metal coated section. The painted section on this side indicates a failure of the paint and a deep pitting of the sheet under the paint. It is of deep interest to note that immediately below the sprayed molten metal a zone of the painted section has been protected by the adjacent sprayed molten metal. This is due to the inhibitive protective value of the zinc metal coating.

FIG. 32.



Note on this side that immediately below the sprayed molten metal a zone of the painted section has been protected from deterioration by adjacent sprayed molten metal.

PROTECTION WITH ALUMINUM.

In addition to the protection provided by the anodic characteristics of Sprayed Molten Aluminum Coatings and their resistance to chemical action, they are also being used to a continually increasing extent for retarding deterioration of industrial equipment which is exposed to the action of high temperatures.

Alumetizing is the application of a coating of sprayed molten aluminum to a surface. By means of a simple chemical process, plus a subsequent heat treatment, the sprayed aluminum penetrates to a considerable depth and produces a ferro-aluminum alloy with a top surface of aluminum oxide. Protection from deterioration is exceptionally effective.

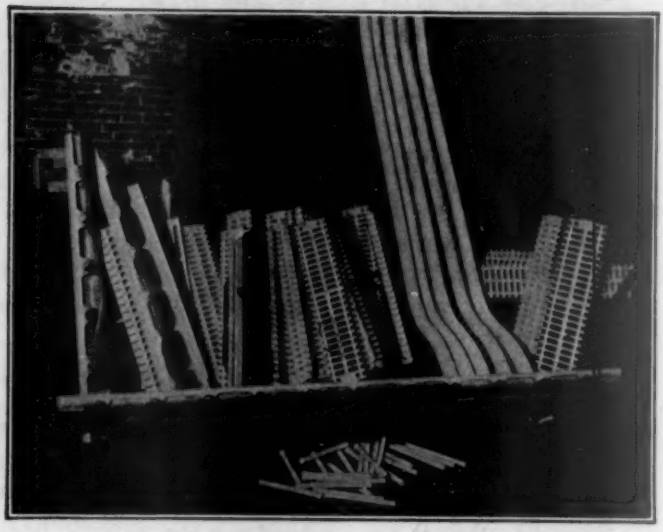
Oxidation in use is retarded. On grate bars, boiler tubes and other furnace equipment adherence of clinker is prevented, thus greatly increasing the efficiency of combustion. In a test made in locomotive service, Alumetized bars required but one-fifth the number of replacements as did plain untreated bars.

Alumetizing with MetaLayeR is established as an absolute necessity in steam generating equipment of the modern high speed liners and naval vessels.

FIG. 33.

Alumetizing—showing stoker tuyeres being sprayed with molten aluminum and heat treated.

FIG. 34.



Locomotive grate bars and arch tubes, protected by spraying with molten aluminum. Uncoated bars lasted about six weeks. Coated bars have been in use three years. Clinkers do not adhere to the alumetized surfaces.

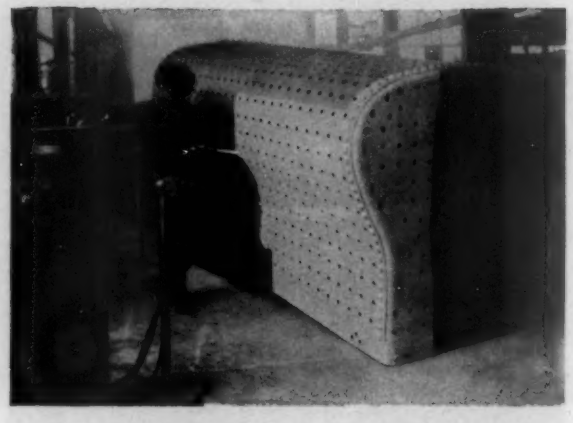
Other successful applications for Alumetizing are: distributors in automatic stokers, condenser tubes, pyrometer couple wells, boiler tube cleaning equipment, gas and electric ovens and muffler parts; rheostats and electric heater resistances, exhaust manifolds; valves, pistons and explosion

FIG. 35.

Protecting expanded ends of condenser tubes and tube sheets from corrosion with molten metal coatings.

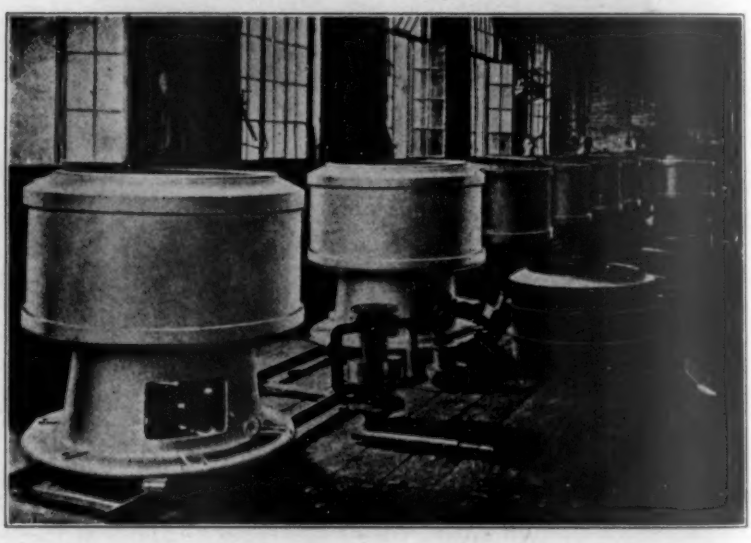
chambers of internal combustion engines; parts exposed to contact with molten glass; varnish kettles, oil refining equipment, superheater units, etc. The durability of such elements has been increased as much as one hundred times by the application of sprayed molten aluminum coatings.

FIG. 36.



Locomotive firebox receiving a double coating of aluminum and zinc. No corrosion is in evidence after two years of service.

FIG. 37.



Coating centrifugals with aluminum. Protects against corrosion and provides good light reflecting surfaces.

FIG. 38.

Developing rail bonding connections on electric railroads. Also preventing loose joints.

FIG. 39.

Storage tanks for oils, chemicals or gases may be advantageously metal coated.

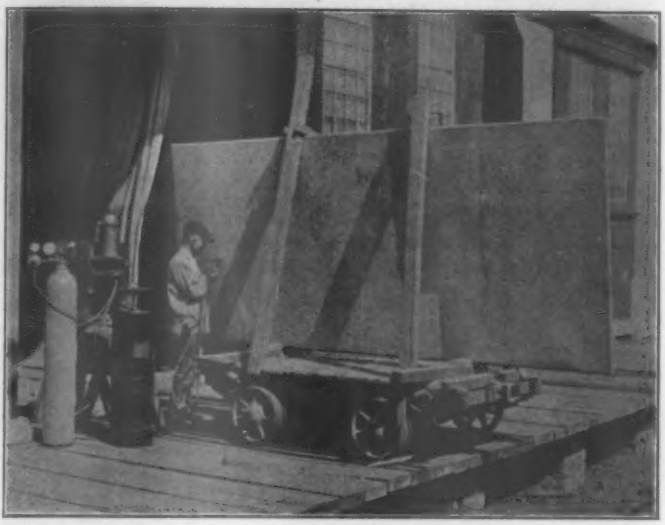
FIG. 40.

Versatility personified. These were coated with one MetaLayeR in one day. Three mixers with aluminum. Four cast iron tanks with lead, two with tin. One steel barrel with copper and one with lead.

FIG. 41.

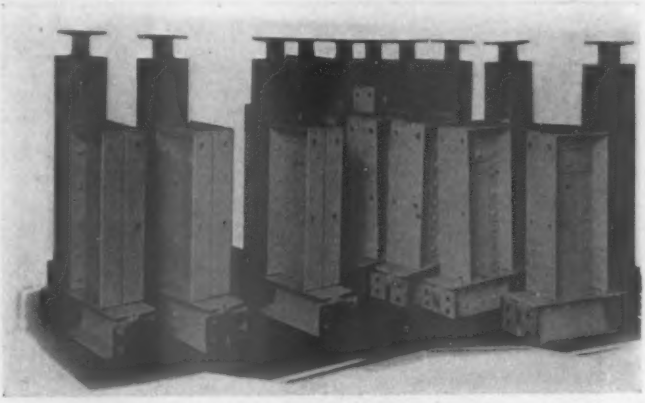
Showing that sprayed molten iron filling defects in steel castings may be chipped or filed.

FIG. 42.



A steam heated dryer plate, used in a vacuum drying oven, protected from corrosion and chemical action by sprayed molten metal coatings.

FIG. 43.

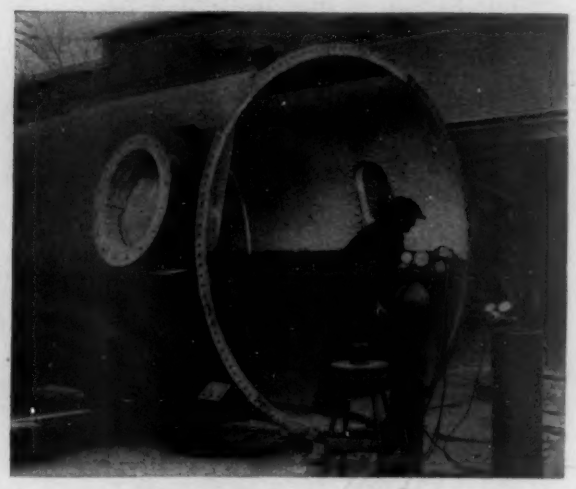


Floor members of Delaware River Bridge, Philadelphia to Camden. About 50, inaccessible for painting, were zinc coated by MetaLayeR.

FIG. 44.

Porous castings repaired. Where chaplet leaks occurred coatings of iron were applied.

FIG. 45.

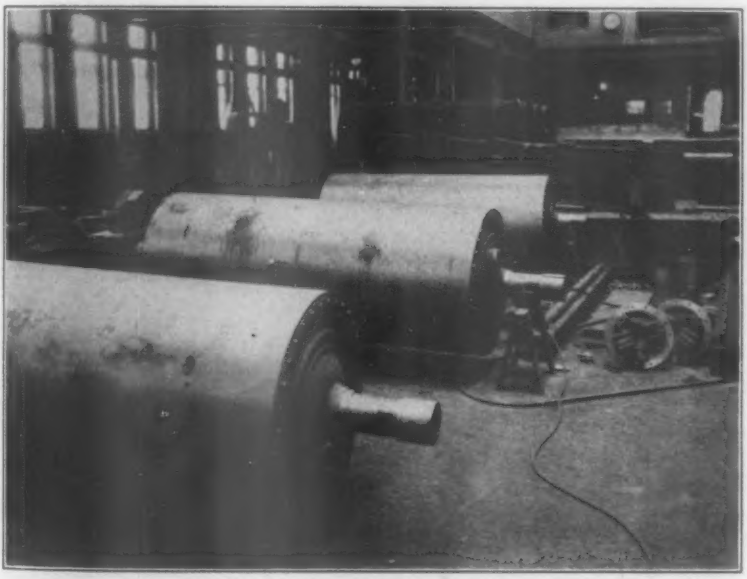


Large gas scrubber has inside coated with sprayed molten lead.
Note that it did not have to be brought indoors.

FIG. 46.

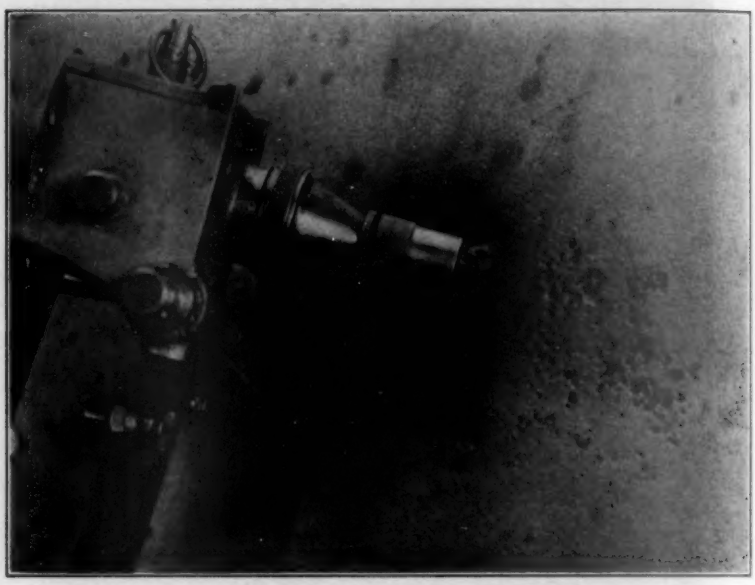
Coating 8 in. wrought iron pipe 25 ft. long with various metals, for oil pipe lines. Thoroughly practical and economical.

FIG. 47.



Expensive Dryer Rolls for Paper Making Machines have defects in finished machined surfaces filled with sprayed molten metal.

FIG. 48.

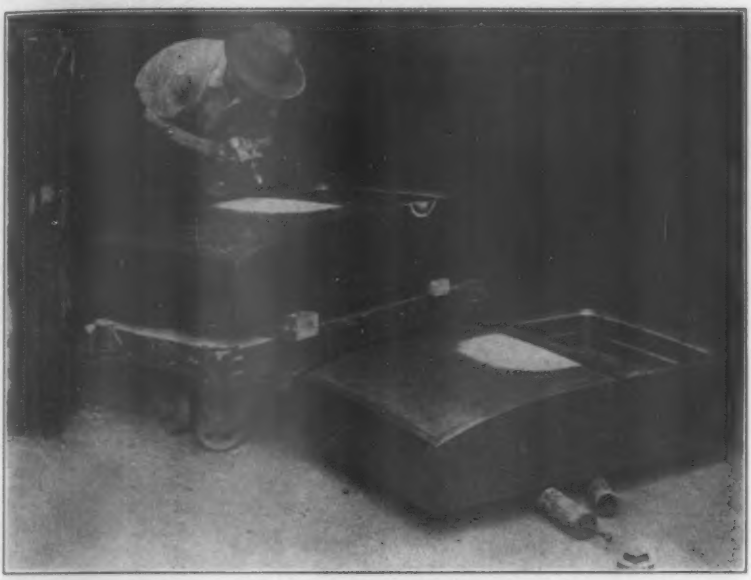


Showing character of defects in the Dryer Rolls which are quickly and satisfactorily repaired.

FIG. 49.

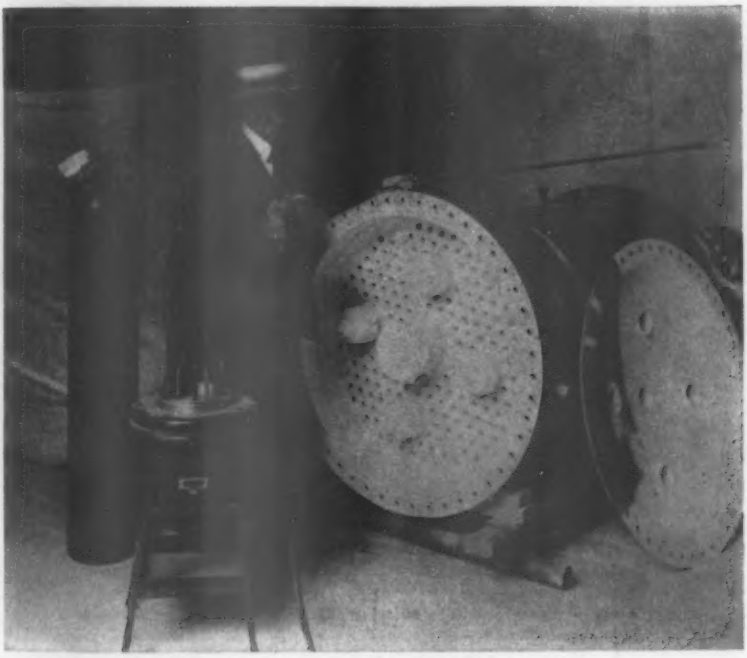
Ash pan for locomotive protected from corrosion by sprayed molten aluminum coatings.

FIG. 50.



Low areas on automobile forming dies coated with sprayed molten metal. Time required—about four hours for each die. Prevented shutting down of entire department if new dies would have been made.

FIG. 51.

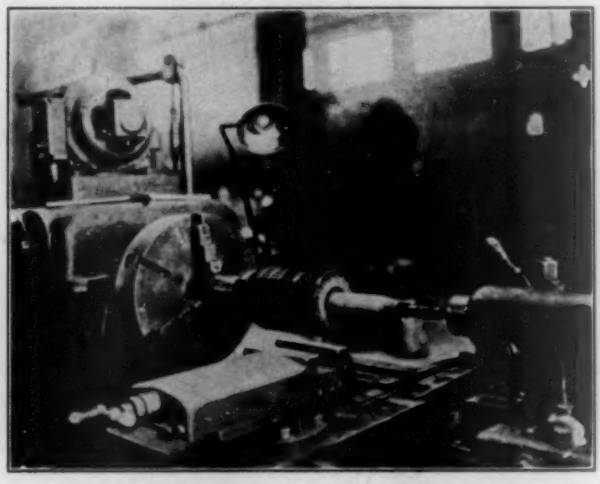


Coating Feed Water Heater with sprayed molten aluminum. The interior surfaces of the 1' diameter tubes were coated for their entire length, using the rotating nozzle.

FIG. 52.

One of six portable equipments used for coating all exposed steel on German States Railroad. Necessarily work is done in the field.

FIG. 53.



Building up worn armature shaft by spraying molten high carbon steel on worn part.

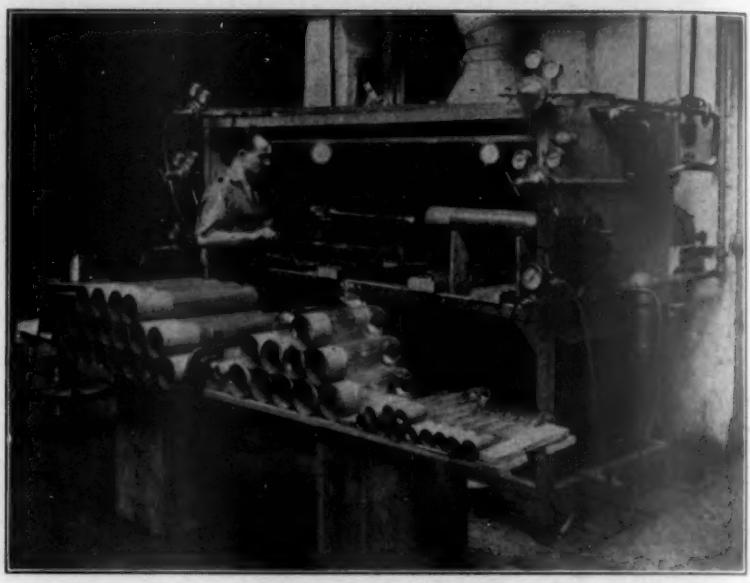
FIG. 54.

Storage battery compartments on submarines are protected from attack of sulphuric acid fumes. Sprayed molten lead was applied.

FIG. 55.

Electric motor castings which had been machined too small were salvaged by applying sprayed molten iron to the undersized parts.

FIG. 56.

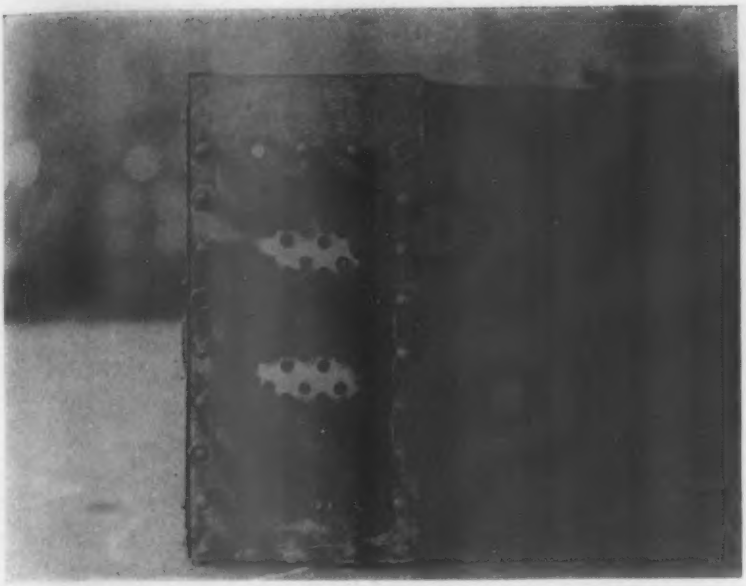


Glass condensers coated inside with sprayed molten lead and outside with lead which was then coated with sprayed molten copper.

FIG. 57.

Locomotive boiler coated inside with sprayed molten zinc, providing excellent protection from corrosion.

FIG. 58.



Saddle type feed water heater. Tube sheet was cracked. An emergency repair using sprayed molten zinc has proven to be permanently satisfactory.

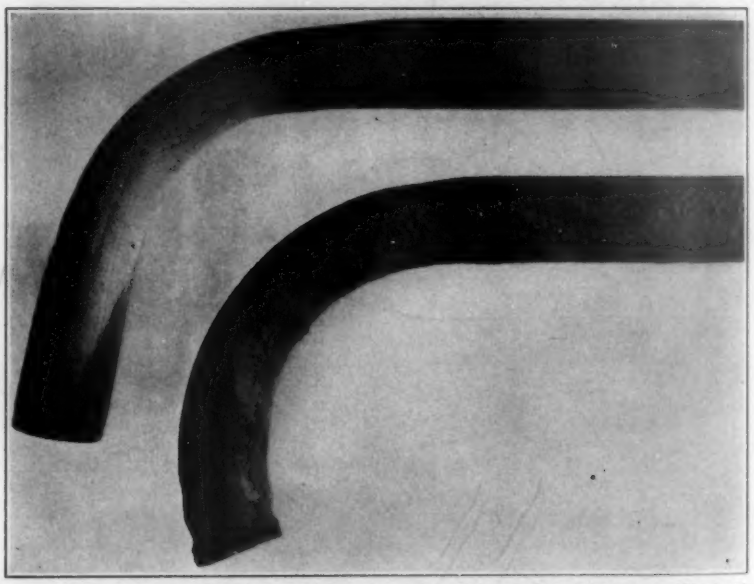
FIG. 59.

Refrigerator coils protected from corrosion with sprayed molten zinc.

FIG. 60.

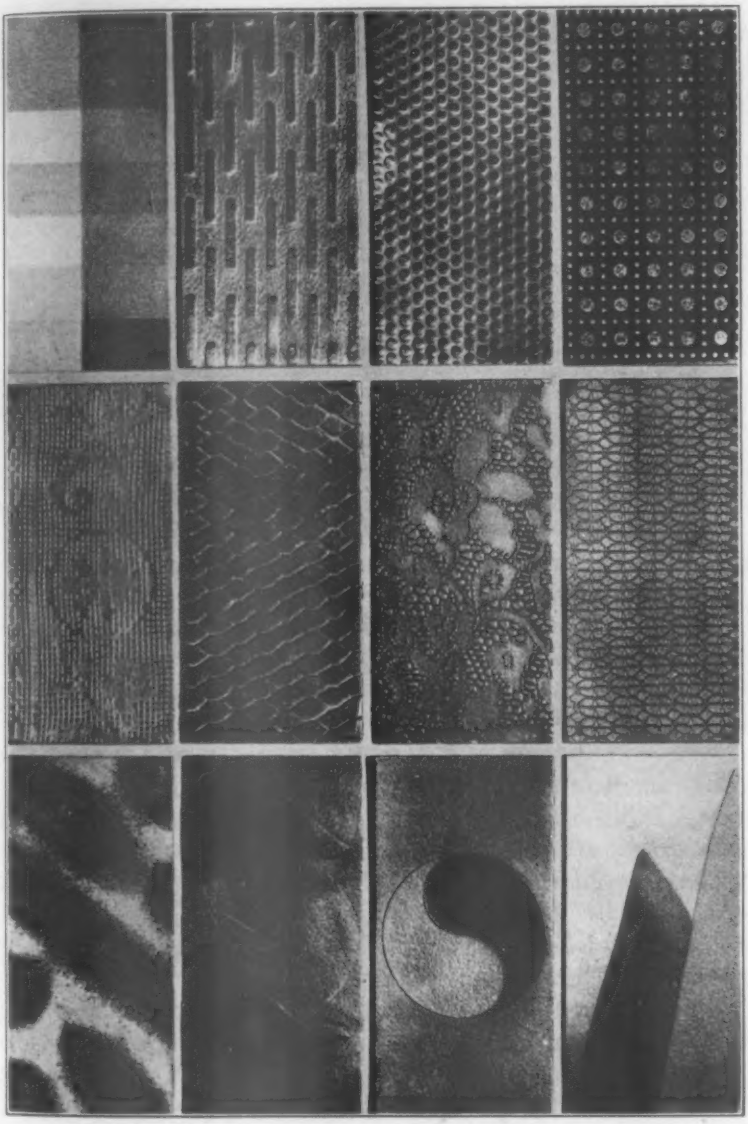
Diesel engine cylinders coated with aluminum alloy of same composition as was used in water jackets, thus eliminating danger of electrolytic action.

FIG. 61.



One sprinkler pipe was painted, the other was coated with sprayed molten zinc. Illustration shows comparative protective value after one year's service.

DECORATIVE METAL COATINGS.
FIG. 62.



In the field of decoration, MetaLayeR has virtually unlimited possibilities. Besides metal trimmings, and the coating of decorative objects, attractive patterns may be produced by means of stencils. Metals of different colors may be used, and by building up coatings, patterns may be produced also in relief. Fig. 62 illustrates a few typical patterns.

INTERIOR VIEW OF METAL COATING PLANT, SHOWING TYPICAL INSTALLATION.

FIG. 63.

Installed Plant for Operation of MetaLayeR. Showing sand blast room, spraying cabinet, etc.

I have not touched on details bearing on the development of accessory equipment used in connection with MetaLayeR. Results secured with commercial accessories quickly emphasized their unsuitability for the requirements.

The providing of abrasives for proper sand blasting, the development of efficient and dependable sand blasting equipment, of water separators, regulating gauges for air, acetylene and oxygen, spray cabinets with ventilating apparatus, etc., involved problems quite as intricate as that covering the perfection of MetaLayeR itself. In fact, I realized that MetaLayeR by itself was like an engine without a boiler, or a lathe without means for operating it.

The creation of a demand for something unknown to industry, of explanatory literature, of an organization to manufacture the equipment and service the process, the development of a sales organization, the solving of problems of distribution on a basis acceptable to customers—these,

when viewed in retrospect, make me wonder how I took care of them all.

Providing a balanced, complete Metal Coating System suitable for meeting the requirements of industry on a commercial scale, has been a man's sized job, and one which I am proud to have solved to the satisfaction of our customers.

On Some Measurements of the Equivalent Height of the Atmospheric Ionized Layer. E. V. APPLETON. (*Proc. Roy. Soc.*, A, 803.) In recent years it has been recognized that radio waves are reflected from an ionized layer of the atmosphere, the Kennelly-Heaviside layer, and the height of this above the surface of the earth has been inferred from effects produced on the waves reflected and later returning to the earth. When waves are emitted they reach a receiving station by two routes, directly and by reflection from the layer and the two trains of waves produce interference effects. By varying continuously the length of waves sent out and by employing loop and antenna receiving systems it has been possible to compare the relative intensities of the two wave trains, to get the angle of incidence of the reflected waves with the ground as well as some knowledge of the polarization of the reflected waves. Further, from a study of the fringes produced the equivalent height of the reflecting layer can be calculated. Especial interest attaches itself to the times of sunset and sunrise. It was, however, impossible to experiment at sunset on account of the many wave-lengths sent out from stations at that part of the day. Before sunrise the interference effects noted indicated the presence of two or more descending rays. "The normal type of nocturnal variation of equivalent height is a slow increase in height after sunset, reaching a maximum value (average 126 km.) at about 30 to 40 minutes before sunrise, after which a rapid reduction in height takes place. Such a variation is of the type we should expect if the upper atmospheric ionization is produced by some type of solar radiation which travels in straight lines (e.g., ultra-violet light). On the cessation of the influence of this radiation after sunset recombination of ions would cause a slow increase in the height of the layer to take place, which would only cease on the advent of sunrise for this particular type of radiation at the height of the lower boundary of the ionized region. The renewed action of this radiation causes a rapid fall of the layer, as deduced from the measurements of equivalent height." There are deviations from this normal procedure. Sometimes the equivalent height stays nearly constant all night at about 100 or 110 km. Again unusually large heights are found during the three or four hours before dawn. There is some reason for believing that in addition to the main ionized region there may be one or more subsidiary ones.

G. F. S.

THE INVISIBLE GOVERNMENT *—OUR WASHINGTON SCIENTISTS AND WHAT WE ARE DOING WITH THEM.

BY

EDWARD EYRE HUNT,

Secretary, Committee on Recent Economic Changes.

During the past nine years I have been privileged to work in Washington and to watch the wheels of Government go round. The thing which I have studied with most interest is a segment of what might be called "the invisible Government." By this I do not mean the lobbyists, social and political, for whom the term was coined; I do not mean the Senators and Representatives on Capitol Hill, most of whose effective work is done in committees; I do not mean the President, who necessarily does much of his work in private. I mean the army of scientists, largest in numbers and in capacity to be found anywhere in the United States—those men, and women too, whose work of low visibility and high potentiality may easily be overlooked on a hasty visit to Washington.

The greatest inspiration of my work in Washington has come from these men. To name them would be an impertinence. To honor them fittingly is beyond my powers. But tonight I want to examine the conditions of their work as a basis for certain tentative conclusions.

I.

Scientists in the Federal Service have first of all the advantage of numbers. The scientific and technical staff of the Bureau of Standards alone is more than 500; and altogether there are about 5,000 in the professional positions in Washington and 7,500 in the field. Scientists in the Federal Service have the further advantage of the presence of a number of cooperating research institutions. Washington is headquarters

* Presented at a meeting held Thursday, March 13, 1930.

of the National Academy of Science and the National Research Council, the latter set up to initiate, correlate and stimulate research. The Carnegie Institution is in Washington. The Institute of Government Research has its offices there. Technical societies have their headquarters or strong local sections in the Capital, so that the research worker finds disinterested fellowship and encouragement from his peers in whatever direction he looks. This is a great advantage.

Security of tenure is another advantage to the scientist. The Government scrutinizes with extraordinary care the qualifications of the person about to enter its service, and once in, the Civil Service protects him.

Facilities and equipment, sometimes unique, are at the disposal of the Government scientist. Nowhere else on earth can he find such a mighty flow of statistical information on thousands of subjects; nowhere else can he find such recording and tabulating machinery as in the Census; such testing equipment as in the Bureau of Standards; such books as are in the Library of Congress.

Perhaps the knowledge that our scientist is serving the whole public is a stimulus and support to him, but I do not press this point. A prominent member of the Cosmos Club was once discussing his work with an eminent petrologist who races about the globe to act as midwife when a volcano gives birth, or to sit at the bedside when an earthquake splits the forehead of Mother Earth. "What a satisfaction it is to the scientist," said the Cosmos Club member, "to know that he is serving the public." "The public!" snorted the petrologist, "why, if I thought that studying volcanoes was any damned use, I'd quit it tonight."

Now, what are the drawbacks to research in the Government service?

With certain conspicuous exceptions research is tolerated rather than systematically and assiduously cultivated.

It is a by-product of the routine repetitive operations of enumerating, describing, measuring, mapping, charting, standardizing and testing.

Financial grants for scientific work are too often temporary. Continuing research suffers from uncertainty as to

funds, yet we need not only research which is well thought out, well organized and well financed, but research which is continuous.

Finally, the scientist sometimes suffers from administrative handicaps. He is seldom free from interruption. He might as well work on the sidewalk as in his office. A friend of mine says: "From the chief of the Bureau to the lowliest scientific worker continual interruption during office hours prevails. It reminds me of a department store in which the president has to stop what he is doing to sell ten cents worth of ribbon." The scientist may himself be loaded with administrative duties. Worse than that, there are still bureaus where almost any Tom, Dick or Harry from outside can march in and waste the time of the chief, but where his scientific subordinates find it difficult to get in and irksome to stay after they crash the gate.

This makes a sound judgment of scientific work a very difficult thing to get. The best man in America is not too good to decide if a new research project is worthy or to pass upon the results of research. The best man in America is not always passing upon such projects today.

Too many poorly planned conferences; too much correspondence are time wasters to which the scientist is slave. But I have said enough to suggest a few handicaps, not to mention salaries often inadequate, retirement funds which are ludicrous, and the apparently ineradicable idea that those in Government employment are in some way or other beneficiaries against whom the Treasury must be safeguarded.

II.

Lack of proportion in the public appreciation of research naturally is reflected in one-sided Governmental programs. In the field of administration, for example, research is hardly out of its infancy. Our Government is the biggest business organization in the United States. It collects and spends more money. It hires more persons. When Mr. Taft was President he once said that its activities were "almost as varied as those of the entire business world." Yet so far as I know only a handful of scientists are working in this vast field of general administration and personnel management.

The Bureau of the Budget and the Efficiency Bureau have usually to meet immediate and pressing needs. The Civil Service Commission, the Treasury Department and the Post Office Department—the latter with a personnel of 375,000—have been developing vastly better personnel methods than we have had in the past. But out of the great governmental experience has there come any proportionate contribution to the science of management in general? Has the Government made any important contribution to personnel administration since the Army Alpha tests? We must admit that it has not. I am convinced, however, that this statement will not be true of the future. Already the Government is planning to put at the disposal of workers, employers and schools the psychological tests and methods which have been revolutionizing the employment methods of the Civil Service. The examination each year of some sixty thousand federal job seekers furnishes the basis for these tests.

In routine statistical work and the research which goes with it the "invisible Government" makes a much better showing. But Congress directs our scientists to describe, to measure, to test, to set standards, rather than to make discoveries. Repetition of a success already achieved is the surest means of securing increased appropriations from Congress and recognition from the public.

In physics, chemistry, technology and engineering, the achievements of the "invisible Government" bulk larger than those of private industry, but not so large as those of the universities. The Departments of Agriculture, Commerce, War and Navy stand out on this honor roll. The nitrogen fixation process, the geodetic establishment of the figure of the earth, the twelve course radio beacon, the aluminum coating for duralumin are examples of some of the achievements of devoted scientists in Government service.

III.

It requires no crystal grazing to see in this only a beginning. I am reminded of a tribute from my small son who watched me dig some granite boulders from our lawn in Connecticut. "Daddy," he said, "when you get done the earth won't be quite round, will it?" I am afraid the earth will still be

round with all the research we can do. But shall be hugging a delusion if we infer that the status of research is secure; that everybody's doing it. Federal research is still too largely incidental to other work. Often it is done outside of the researcher's office hours, on his own time. Anything like a well-rounded, publicly recognized and officially supported program is still to come.

Yet our needs are growing at a great rate. Pure science, as Dr. George Otis Smith has happily said, is "not-yet-applied science." There are enormous fields which are receiving little or almost no attention, private or public. Certain backward industries seem almost totally unaware of the value of research. One of our greatest and most famous corporations never bothered about research at all until three or four years ago. In the programs fostered by many of the States of the Union agricultural research is almost alone. Few of our municipalities do any research at all. Yet in no country of the world is research so important as in America. In no country in the world should there be more concern about maintaining and advancing wages and living standards, and this can only be done by scientific pioneering, by well-planned thrusts into the great unknown.

I doubt if we can safely leave all this to private initiative. The need for action is already so obvious that we must plan to utilize all our agencies, all our resources.

The best estimate that I can make leads me to think that all the research and promotional activities of the Government put together costs less than two cents of the taxpayer's dollar. President Hoover when Secretary of Commerce stated that these activities "are bringing to the American people in added national wealth and bringing directly into the treasury literally hundreds of millions of dollars, or perhaps even a larger figure—billions in increased national wealth on one side, and hundreds of millions of dollars in available taxes on the other."

Mr. Owen D. Young recently testifying before a Senatorial committee said: "I can go to my directors and can make recommendations for research and can get appropriations promptly and expend them, while if I were at the head of a Government-owned company I would have to come to

Congress and go before forty-eleven committees and in the end probably not get the money asked for or needed."

IV.

How little we know of what detonates the brain worker! How much of a help or a hindrance financial security may be, privacy may mean! I would like to see as a research project, the processes of research in the Government service; the why and how of past achievements and a determination of the degree to which favorable conditions are or are not provided today. Our vast building program now going on in Washington is doubtless providing better facilities. Some day, let us hope, there will be widespread recognition of the importance of these things, and actual competition in furnishing an environment for creative work.

But without waiting for this Utopian solution perhaps I may venture a few obvious suggestions. First, the "invisible Government" must be made visible. It must be encouraged and assisted in its task of winning public attention and public support. Furthermore, it should be possible to make provision so that a larger portion of Federal appropriations can be ear-marked for research. If research is weak in the field of administration, that branch can be strengthened. If general routine is encouraged at the cost of originality, that can be recognized and the tendency can at least be discussed. There might be established a preferred list of scientists in the Government service whose previous activities had entitled them to recognition, a part of whose time might be freed from present routine for original work. Older and more experienced men might be treated as fellows of the bureau or department in which they have served with distinction.

Periodic leave from the Government service to undertake outside research projects might contribute to the same end. I have heard of at least one former Secretary of a great department who thought that if a bureau could release a specialist for six months' of scientific work outside the service, it could and should dispense with him altogether. Such an attitude is not only preposterous; it is suicidal.

We might deliberately develop agencies of State and municipal research on a national scale.

For many of the results of research the community must wait for its dividends, but as our civilization develops the time interval between expenditures and the application of the results grows less and less and the dividends grow larger and larger.

Out of our dollar in taxes you and I get about eighty-seven cents worth of policing, past or present, through the Army and Navy, the Coast Guard, the administration of the pure food laws, the immigration service, the prohibition unit, and many others. We get eleven cents worth of special services, such as the weather reports, the postal service and lighthouses. We do not expect a dividend on these varied operations. They are not reproductive. We are satisfied to get good service at reasonable rates.

But scientific research is reproductive. What we get for the two cents which are left after the policeman and the functionary have been paid is incalculable. It gives us at least 200 per cent. in dividends. It may be made to give more. Only two cents of our dollar! Yet it is to this tiny sum spent by the Federal Government that The Franklin Institute as a great scientific body and the American people as a whole must look for an explanation of part of the strength of our national economy and for a vital portion of its future promise.

A Procedure for Measuring the Refractive Index of X-Rays. K. KELLERMANN. (*Ann. der Phys.*, Vol. 4, No. 2.) After the interference experiments of Laue, Friedrich and Knipping had demonstrated the wave-nature of X-rays their indices of refraction were determined in different ways. A table of results is presented in which the following methods were used: departure from Bragg's law, total reflection from a revolving plane surface, total reflection of a diverging beam from a plane surface at rest and the diminution of the emission of photo-electrons at the limiting angle of total reflection. In all cases the refractive index is less than unity. It is customary to designate by δ the difference between the index and 1. The largest angle between the plane of the reflecting surface and the incident ray at which the latter is totally reflected is called α. Of the substances whose indices are recorded in the table mica has the largest values for δ. For X-rays of wave-length 1.5 A. it is 9.35×10^{-6} and grows with increasing wave-length until for a length of 8.3 A. it attains the value of 249×10^{-6}. For the same substance the two limiting angles for total reflection are respectively 14.9′ and 1° 16.7′. For wave-length 1.5 A. iron pyrites possesses a larger value of δ than mica.

A beam of X-rays from a small source falls on a cylinder whose axis is at right angles to the rays. Over a small part of the cylindrical surface the rays are totally reflected and are incident on a photographic plate which records them. From the geometrical constants of the arrangement and the dimensions of the recorded patch it is possible to deduce the index of refraction and the critical angle. The cylindrical surfaces had large radii and were produced by slightly deforming thin plane sheets. The wave-length used was in all cases 1.537 A. The following results were obtained

Material.	α.	δ.
Crown Glass	12.6′	6.7×10^{-6}
Silver	25.5	27.5
Glycerine	9.5	3.8
$CaCl_2$ Solution	10.4	4.6

G. F. S.

DYNAMICAL ANALYSIS OF MACHINES.*

BY

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E. I. DuPont de Nemours & Company,
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ON THE CALCULATION OF INTERNAL REACTIONS IN A MACHINE WITH AGGREGATE MOTION FIG. 56.

When any member or combination of members of a machine are driven by external means, the resultant motion is compounded of the motion of each driving point, assuming the other driving point fixed. The motion of the driving points themselves for a machine with one degree of freedom are geometrically connected through the other members external to the member or members under consideration.

This suggests the application of Lagrange's equation for the calculation of the internal reactions, for we may at first consider the motion of each driving point as an independent coördinate and the motion of the member or system of members as a function of these coördinates. Thus the aggregate system has as many degrees of freedom as the number of driving points. We then by Lagrange's equation may calculate the internal reaction at any driving point as an external reaction to the aggregate member or members under consideration and acting on the coördinate of the driving point. Finally, by the overall kinematic relations, we substitute the motion of the driving point as a function of the fundamental coördinate of the system.

As an example of the application of this principle, we will consider a Walschaert walve gear so extensively used on locomotives. The piston valve is driven through an aggregate combination by the combining lever connection at the main crosshead and by a small crank on the main driver, Fig. 56.

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* Extension of a portion of a dissertation for the degree of doctor of philosophy submitted to Clark University, 1928.

Continued from p. 831, vol. 209, June, 1930.

In estimating the equivalent inertia effect as an additional reciprocating mass at the crosshead and the reacting moment at the crank, it is necessary to estimate the reaction of the valve gear at the crosshead and its moment effect at the crank.

Let m = mass of the piston valve, valve stems, etc.
P = reaction of the valve gear at the crosshead,
Φ = driving moment at the crank,
θ = valve gear crank angle,
x = displacement of piston from its mid position,
s = displacement of valve from mid position,
l = length of combining lever,
r = radius of valve gear crank.

The kinematic relations are approximately obtained by considering separately the motion given to the valve when the other driving point is fixed and then combining these motions for the aggregate motion.

Thus for the component motion due to the crank:

$$s = -\frac{a}{l} \cdot \frac{u}{c} \cdot r \sin \theta$$

$$s_x = \frac{b}{l} x,$$

$$\therefore \quad s = -\frac{a}{l} \cdot \frac{u}{c} \cdot r \sin \theta + \frac{b}{l} x.$$

Now x and θ are ultimately connected by the propotions of the main rod L and the crank radius. We note the main driving crank at right angles with the valve gear crank, so that main crank angle $\phi = 90 + \theta$.

Neglecting the obliquity of the connecting rod in a first approximation:

$$x = R \cos \theta$$

Therefore,

$$s = -\frac{a}{l}\frac{u}{c} r \sin \theta + \frac{b}{l} R \cos \theta,$$

where u is a variable, so that we can adjust for the required angle of advance.

Let $\frac{u}{c} = K$ (that is, the gear ratio to the combining lever), then the velocity of the valve, is:

$$\dot{s} = -\frac{a}{l} K \cos\theta \dot{\theta} \frac{b}{l} \dot{x}.$$

In order to simplify the problem, we will assume very approximately that the inertia of the valve gear system is concentrated at the piston valve, so that the kinetic energy becomes:

$$T = \tfrac{1}{2} \Sigma m \dot{s}^2.$$

The equations for the driving reactions are, therefore,

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{x}}\right) - \frac{\partial T}{\partial x} = P, \tag{1}$$

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{\theta}}\right) - \frac{\partial T}{\partial \theta} = -\Phi \tag{2}$$

and since

$$\dot{s} = -\frac{a}{l} Kr \cos\theta\dot{\theta} + \frac{b}{l}\dot{x},$$

$$T = \frac{m}{2}\left(\frac{a^2}{l^2} K^2 r^2 \cos^2\theta\dot{\theta}^2 - \frac{2abK}{2} r \cos\theta\dot{\theta}\dot{x} + \frac{b^2}{l^2}\dot{x}^2\right),$$

$$\frac{\partial T}{\partial \dot{x}} = m\left(-\frac{ab}{2} Kr \cos\theta\cdot\dot{\theta} + \frac{b^2}{l^2}\dot{x}\right),$$

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{x}}\right) = m\left(-\frac{ab}{l^2} Kr \cos\theta\cdot\ddot{\theta} + \frac{ab}{l^2} Kr \sin\theta\cdot\dot{\theta}^2 + \frac{b^2}{l^2}\ddot{x}\right) = P$$

since $\frac{\partial T}{\partial x} = 0$.

If now we assume $\theta = \omega =$ constant:

$$P = m\left(Kr \sin\theta\cdot\omega^2 \frac{ab}{l^2} + \ddot{x}\frac{b^2}{l^2}\right).$$

Substituting $\ddot{x} = -R\cos\theta\cdot\omega^2$, we have finally:

$$P = m\omega^2\left(Kr\frac{ab}{l^2}\sin\theta - \frac{b^2}{l^2} R\cos\theta\right)$$

for the reaction of the valve gear (or more strictly the piston valve inertia) at the crosshead.

To calculate the torque reaction of the gear at the crank, we have:

$$\frac{\partial T}{\partial \dot{\theta}} = m\frac{a^2}{l^2}K^2r^2\cos^2\theta\cdot\dot{\theta} - m\frac{ab}{l^2}Kr\cos\theta\cdot\dot{x},$$

$$\frac{d}{dt}\frac{\partial T}{\partial \dot{\theta}} = m\frac{a^2}{l^2}K^2r^2\cos^2\theta\ddot{\theta} - 2m\frac{a^2}{l^2}K^2r^2\sin\theta\cos\theta\dot{\theta}^2 + m\frac{ab}{l^2}Kr\sin\theta\dot{\theta}\dot{x} - m\frac{ab}{l^2}Kr\cos\theta\cdot\ddot{x},$$

$$\frac{\partial T}{\partial \theta} = -m\frac{a^2}{l^2}K^2r^2\sin\theta\cos\theta\dot{\theta}^2 + \frac{ab}{l^2}Kr\sin\theta\dot{\theta}\dot{x},$$

$$\therefore\ \Phi = m\frac{a^2}{l^2}K^2\cos^2\theta\ddot{\theta} - m\frac{a^2}{l^2}K^2r^2\sin\theta\cos\theta\dot{\theta}^2 - m\frac{ab}{l^2}Kr\cos\theta\ddot{x}.$$

Assuming uniform velocity of the crank, $\theta = \omega =$ constant, and noting, then

$$\dot{x} = -R\sin\theta\cdot\omega \quad \text{and} \quad \ddot{x} = -R\cos\theta\cdot\omega^2,$$

the torque reaction on the crank reduces to

$$\Phi = -m\left(\frac{a^2}{l^2}K^2r^2\sin\theta\cos\theta - \frac{ab}{l^2}KRr\cos^2\theta\right)\omega^2.$$

These expressions can be readily verified by a direct derivation.

METHODS OF INERTIA FORCE RESOLUTION.

In the calculation of the reactions on a member we may either estimate the resultant accelerating forces, or by D'Alembert's principle, take the reversed effective forces as corresponding inertia loadings, thus reducing the external forces and the inertia loadings to a system of kinetic equilibrium.

The fundamental equations for the derivation of all inertia loadings are

$$\Sigma X = \Sigma m\ddot{x}, \qquad \Sigma Y = \Sigma m\ddot{y}$$

and

$$\Sigma L = \Sigma(Yx - Xy) = \Sigma m(\ddot{y}x - \ddot{x}y),$$

where ΣX, ΣY and ΣL are reactions and the moments of the reactions, at the joints.

First, if we consider the resolution with respect to the center of gravity, i.e., the origin of the coördinates assumed at the c. of g., then we have a translatory vector through the c. of g., $\overline{R}$, with components $X = -M\ddot{x}_g$ and $Y = -M\ddot{y}_g$, together with a couple or moment

$$L_g = -I_g\ddot{\theta} = -Mk_g\ddot{\theta}, \qquad \ddot{\theta} = \text{ang. accel. of member.}$$

Second, for the motion with respect to an axis not through the c. of g. then the translatory effect is

$$\overline{R} = -M(\bar{a}_0 + \overline{r\ddot{\theta}} + \overline{r\dot{\theta}^2}),$$

where $\bar{a}_0 \equiv \left|\begin{matrix}\ddot{x}_0 \\ \ddot{y}_0\end{matrix}\right|$ = accel. of axis, and r = dist. from axis to c. of g. together with a moment

$$-L = I_g\ddot{\theta} + M(\ddot{y}_0(x_g - x_0) - \ddot{x}_0(y_g - y_0)).$$

The translatory vector R may be regarded as acting through the c. of g. and compounded from three vector components

$$\overline{F}_1 = -\overline{Ma_0}, \qquad \overline{F}_2 = -\overline{Mr\dot{\theta}^2} \quad \text{and} \quad \overline{F}_3 = -\overline{Mr\ddot{\theta}}.$$

The moment of these vectors about the axis is obviously equal to the second term of the right side of the moment equation. We note $\overline{F}_2$ has no moment about the axis. To account for the first term of the moment equation we must introduce a couple (which in no way affects the translatory effect). If we take the forces of the couple as equal to F_3, then,

$$-I_g\ddot{\theta} = -Mk_g^2\ddot{\theta} = F(e - r),$$
$$\therefore \quad F_3e = -M(r^2 + k_g^2)\ddot{\theta}$$

and

$$r(e - r) = k_g^2 \quad \text{or} \quad e = r + \frac{k_g^2}{r},$$

so that $\overline{F}_3$ acts at the center of percussion. The resolution

is shown in Fig. 57*a* and the resultant resolution in Fig. 57*b* where we note the vector F_1 acting through the c. of g. and parallel to the acceleration of the axis accounts for the acceleration of the axis.

Third, when the horizontal and vertical accelerations are estimated along the rod, the accelerations at any point may be stated in terms of the terminal accelerations at A and B:

If Z_g is the distance from A to the c. of g., then:

$$X = \sum_0^l m\left(\ddot{x}_a - (\ddot{x}_a - x_b)\frac{Z}{l}\right) = M\left(\ddot{x}_a - (\ddot{x}_a - \ddot{x}_b)\frac{Z_g}{l}\right),$$

$$Y = \sum_0^l m\left(\ddot{y}_a + (\ddot{y}_b - \ddot{y}_a)\frac{Z}{l}\right) = M\left(\ddot{y}_a + (\ddot{y}_b - \ddot{y}_a)\frac{Z_g}{l}\right),$$

or if u_a and u_b are the equivalent masses reduced at the ends;

$$X = \mu_a\ddot{x}_a + \mu_b\ddot{x}_b \quad \text{and} \quad Y = \mu_a\ddot{y}_a + \mu_b\ddot{y}_b$$

where,

$$\mu_a = M\frac{l - Z_g}{l} \quad \text{and} \quad \mu_b = M\frac{Z_g}{l}.$$

The horizontal and vertical inertia loading distributed along the rod may be reduced to separate single resultant forces, horizontally and vertically, of magnitude X and Y respectively, and acting at distances Z_h and Z_v from the axis A. It is to be noted in general Z_h and Z_v are not the same.

To find the points of applications of the resultant components X and Y, we take moments about A:

$$Z_hX = \sum m\left(\ddot{x}_a - (\ddot{x}_a - \ddot{x}_b)\frac{Z}{l}\right)Z$$

$$= M\ddot{x}_aZ_g - \left(\frac{\ddot{x}_a - \ddot{x}_b}{l}\right)\sum mZ^2,$$

but

$$\sum mZ^2 = Mk_A^2 = MZ_ge$$

where e is the center of percussion with respect to A.

$$\therefore \quad Z_h = \left(\frac{(l - e)\ddot{x}_a + e\ddot{x}_b}{(l - Z_g)\ddot{x}_a + Z_g\ddot{x}_b}\right)\cdot Z_g.$$

Likewise,

$$Z_v Y = \Sigma m \left(\ddot{y}_a + (\ddot{y}_b - \ddot{y}_a)\frac{Z}{l} \right) Z$$

$$= M\ddot{y}_a Z_g + \left(\frac{\ddot{y}_b - \ddot{y}_a}{l} \right) \Sigma m Z^2,$$

$$\therefore \quad Z_v = \left(\frac{(l-e)\ddot{y}_a + e\ddot{y}_b}{(l - Z_g)\ddot{y}_a + Z_g \ddot{y}_b} \right) Z_g.$$

When the acceleration component of the axis A is nil, evidently $Z_h = Z_v = e$; that is, the point of application of X and Y is at the center of percussion as we should expect.

The resultant components X and Y acting from the axis at distances Z_h and Z_v respectively, decompose into components at the ends of the rod, such that:

$$X_a = \left(\frac{l - Z_h}{l} \right) X \quad \text{and} \quad X_b = \frac{Z_h}{l} X,$$

$$Y_a = \left(\frac{l - Z_v}{l} \right) Y \quad \text{and} \quad Y_b = \frac{Z_v}{l} Y.$$

These components may be considered either as the equivalent inertia loadings at the ends, or as the necessary applied forces acting at the ends for a complete balance of the inertia forces of the rod.

For the inertia forces or loading of the connecting rod of a reciprocating engine, we have some simplification. Since $y_a = 0$ at the crosshead end of the rod, the vertical throw $\overline{Y}$ acts at the center of percussion at distance e from the axis. The acceleration at the crank pin, assuming uniform rotation of the crank, is:

$$\ddot{y}_b = \omega^2 r \sin \phi \quad \text{and} \quad x_b = -\omega^2 r \cos \phi,$$

while at the crosshead pin:

$$\ddot{x}_a = -\omega^2 r \left(\cos \phi + \frac{r}{l} \cos 2\phi \right),$$

where

ϕ = crank angle, ω = ang. vel., and r = crank throw.

Therefore,

$$Z_k = \frac{l^2 \cos\phi + (l-e)r\cos 2\phi}{l^2\cos\phi + (l-Z_g)r\cos 2\phi}.$$

4. When the end acceleration components and angular acceleration are given. Fig. 58.

The translatory effect may be conveniently resolved into components at the ends or joints A and B, where the translatory force is measured in terms of the accelerations at A and B. In view of the relations:

$$\mu_A + \mu_B = M,$$
$$\mu_A x_A + \mu_B x_B = M x_g \quad \text{and} \quad \mu_A y_A + \mu_B y_B = M y_g$$

and if l = length of rod between A and B, while Z_g is the distance measured from A to the center of gravity, then, the translatory vector becomes in magnitude and direction only:

$$R = -Ma \equiv -\begin{vmatrix} \mu_A \ddot{x}_A + \mu_B \ddot{x}_B \\ \mu_A \ddot{y}_A + \mu_B \ddot{y}_B \end{vmatrix},$$

where

$$\mu_A = M\frac{l - Z_g}{l} \quad \text{and} \quad \mu_B = M\frac{Z_g}{l}.$$

The point of application of the resultant of these components, however, does not in general pass through the center of gravity and the mass points μ_A and μ_B are not in general equivalent to the actual inertia distribution of the rod. This resolution only holds so far as the translatory effect alone is concerned.

For the kinetic reaction due to the angular motion, the moment of the resolved components at A and B about the center of gravity must be "corrected" with a "correction couple," so that the sum of the moments of the components and the correction couple equals the kinetic torque reaction of the member itself about its center of gravity.

We note that:

$$\overline{\ddot{x}_A} + \overline{\ddot{y}_A} \equiv \overline{\ddot{x}_g} + \overline{\ddot{y}_g} + \overline{z_g\ddot{\theta}} + \overline{Z_g\dot{\theta}^2},$$
$$\overline{\ddot{x}_B} + \overline{\ddot{y}_B} \equiv \overline{\ddot{x}_g} + \overline{\ddot{y}_g} + \overline{(l - Z_g)\ddot{\theta}} + \overline{(l - Z_g)\dot{\theta}^2}.$$

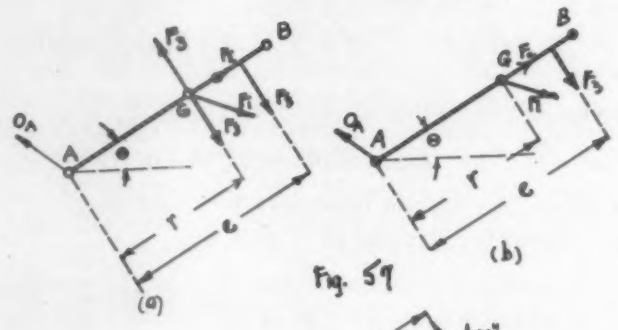

Fig. 57

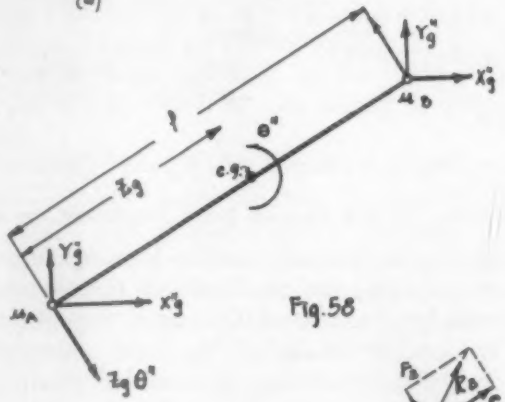

Fig. 58

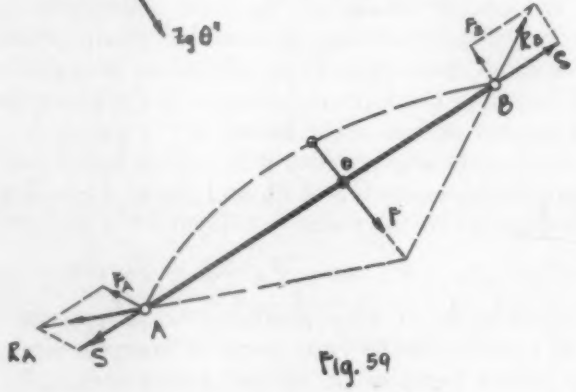

Fig. 59

We then have, for the correction couple, noting the moments of $\mu_A\ddot{x}_g$, $\mu_B\ddot{x}_g$, etc., and the centripetal components are nil about the center of gravity:

$$L_c = L_g - (\mu_A Z_g^2\ddot{\theta} + \mu_B(l - Z_g)^2\ddot{\theta})$$
$$= M\left[k_g^2 - \frac{l - Z_g}{l}\cdot Z_g^2 - \frac{Z_g}{l}(l - Z_g)^2\right]\ddot{\theta}$$

or in terms of the radius of gyration about A, $= k$,

$$L_c = M(k^2 - lZ_g)\ddot{\theta}.$$

Therefore, the inertia resistance revolves into:
The translatory vectors at A and B:

$$\begin{matrix} -\mu_A\ddot{x}_A & -\mu_B\ddot{x}_B \\ -\mu_A\ddot{y}_A & -\mu_A\ddot{y}_B \end{matrix}, \quad \text{where} \quad \begin{vmatrix} \mu_A = M\dfrac{l - x_g}{l} \\ \mu_B = M\dfrac{x_g}{l} \end{vmatrix}$$

and a couple:

$$L_c \equiv -M[k_g^2 - (l - Z_g)Z_g]\ddot{\theta} = -M(k^2 - lZ_g)\ddot{\theta}.$$

1. THE NATURE OF THE END OR JOINT REACTIONS ON MEMBERS.

The kinetic reactions or inertia loadings are treated as applied forces; that is, the resultants of the reversed effective forces are considered as external forces acting on the members.

When a member is loaded by some externally applied force F, Fig. 59, the reactions at A and B must balance the resultant applied load F. This condition is met by the triangle of forces, or the force polygon, with the space diagram giving the lines of action of the forces.

Therefore, a simple resolution is given by R_A and R_B resolved into components S and F_A and S and F_B at A and B, axially and parallel to the force F. Then

$$F_A + F_B = F \quad \text{and} \quad F_A \cdot OA = F_B \cdot OB.$$

By the principle of superposition we may resolve any member of applied forces into parallel components at the ends with direct tension or thrust components S. It is important to note the parallel components are invariable, i.e., $F_A + F_B = F$ and $F_A \cdot OA = F_B \cdot OB$, while the direct

thrust or tension components at the ends can be of any value. The invariable components are determined by the applied loads on the bar itself, while the thrust or tension components are determined by the conditions extraneous to the bar. Therefore, the equal and opposite reactions exerted by the bar on external bodies at A and B consist of the reaction of the parallel components at A and B and the reaction of the thrust or tension along the bar.

The advantage of this method of resolution comes when we consider an assemblage of linkages, with pin connected joints. The reactions of the members on the pins consists of the parallel components loadings of the applied forces on the members, together with the direct tension or thrust components. Thus the inertia loadings, weights, etc., of the members are transferred to equivalent loadings on the pins and we have a system of loaded points at the pints with invariable connections resulting in reactions of constraints along the members; that is, the direct tension or thrust components.

As an example completely illustrating this resolution of the reactions, consider a simple four bar linkage with applied torques T_A and T_B on shafts A and B, Fig. 60.

The inertia loading of the connecting rod will be divided into horizontal and vertical components, Fig. (60a). The horizontal and vertical components required for the balance of these forces are F_{Ah} and F_{Av} at A and F_{Bh} and F_{Bv} at B. In addition, we have an interminate thrust components S, which depends upon the extraneous conditions to the connecting rod.

To determine the thrust components we now consider the crank A or the crank lever B, Fig. (60 b, c).

$$T_A - F_{Ah}r \sin\theta + F_{Av}r \cos\theta - Sr \sin(\theta - \psi) = - I_A\ddot{\theta}$$

so that,

$$S = \frac{T_A + I_A\ddot{\theta} - F_{Ah}r \sin\theta + F_{Av}r \cos\theta}{r \sin(\theta - \psi)}$$

and for the crank lever:

$$Sr \sin(\phi + \psi) - F_Br \cos\phi - F_{Bv}r \sin\phi - T_{Bv} = I_B\ddot{\phi}.$$

The reactions of the connecting rod on the pin joint at A and B are shown in Fig. 60c. Evidently, the inertia loadings of the rod are transferred as equivalent loadings F_A and F_B on the pins, together with a direct thrust or tension S.

The analytical method of resolution of the terminal reactions on a member is the division into horizontal and vertical or X and Y components. Then, if ϕ is the angle F makes with the vertical,

$$X_1 - X_2 = \sum F \sin \phi, \qquad Y_1 - Y_2 = \sum F \cos \phi,$$
$$(Y_2x_2 - X_2y_2) - (Y_1x_1 - X_1y_2) - \sum Fr_p = 0,$$

where r_p is the perpendicular component from the origin of moments to the line of action of F.

Since the reactions at A and B must be equivalent to a force equal and opposite to the applied force F, we have a variety of resolutions of the reactions acting on the ends.

In the member, Fig. 61a, the parallel component is taken equal and opposite to the applied force F acting at the end B. To balance the couple Fb, we may introduce an equal and opposite couple $Pl \cos \theta = F \cdot b$.

In addition, we have an unknown tension or thrust component S. Therefore, the reactions at A and B are the vector sum of these components.

$$\overline{R}_A = \overline{S} + P \quad \text{and} \quad \overline{R}_B = \overline{S} + \overline{F} + \overline{P}.$$

In member, Fig. (61b) for the parallel components $F_B - F_A = F$ and for the corresponding couples and the balancing couple, we have:

$$Pl \cos \theta = F_B b + F_A \cdot a.$$

In addition, we have the thrust or tension component S the reactions at A and B are, therefore,

$$\overline{R}_A = \overline{S} + \overline{F}_A + \overline{P}, \qquad R_B = \overline{S} + \overline{F}_B + \overline{P}.$$

Given the vector reaction of the joint A or B and assuming an arbitrary value for one of the inertia components F_A or F_B, we have four equations for the determination of the unknown thrust S, the inertia component F_B or F_A, the balancing component P and the vector reaction of the joint B or A.

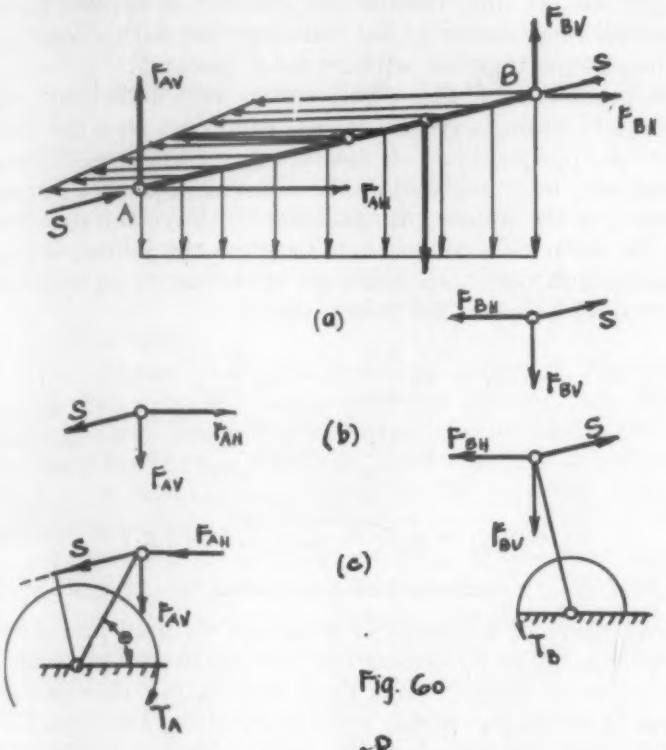
F_{BV}
B
S
F_{BH}
F_{AV}
F_{AH}
S
A
(a)
F_{BH}
S
F_{BV}
S
F_{AH}
(b)
F_{AV}
F_{BH}
S
F_{BV}
S
F_{AH}
(c)
F_{AV}
T_B
T_A

Fig. 60

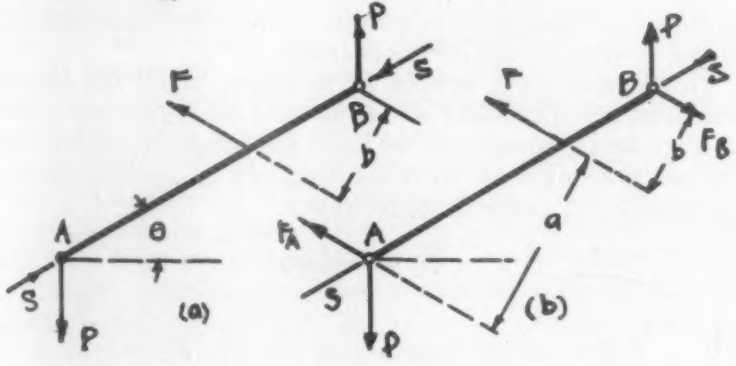
P
F
S
B
b
A
θ
S
P
(a)
P
F
B
S
b
F_B
a
F_A
A
S
P
(b)

Fig. 61

In general, we may resolve any number of applied forces into parallel components at the ends together with a resulting balancing couple together with an axial thrust S.

The reactions of the components, which balance the kinetic reactions and external forces, which act on a member, react on the pin joints of an assemblage of linkages. These reactions may be considered as the equivalent inertia loading transferred to the joints. In addition, we have the reactions due to the invariable connections between the joints, so that the tension or thrust components are of the nature of reactions of constraints between the joints; that is

$$S_{12x} = \lambda_{12}\frac{\partial f_{12}}{\partial x_1} = -\lambda_{12}\frac{\partial f_{12}}{\partial x_2},$$

$$S_{12y} = \lambda_{12}\frac{\partial f_{12}}{\partial y_1} = -\lambda_{12}\frac{\partial f_{12}}{\partial y_2},$$

where

$$f_{12} = \sqrt{(y_2 - y_1)^2 + (x_2 - x_1)^2} - l_{12}.$$

2. AGGREGATIONS OF MEMBERS.

In the study of a system of members we may proceed in a synthetic analysis by considering the separate equations of motion of each member and then eliminating the internal reactions between the parts, thus establishing the equations of motion of the system as a whole, or by a direct consideration of the system of members collectively.

In considering a system of members, since the internal reactions are eliminated so far as their effects on the system as a whole are concerned, we have the simple condition, that the reactions external to this system are in equilibrium with the kinetic reactions of the members.

(*To be continued*)

COMMITTEE ON SCIENCE AND THE ARTS.

ABSTRACTS OF REPORTS.

SUPER-RESISTANT GLASSES.

HALL OF THE INSTITUTE,
PHILADELPHIA, March 7, 1928.

No. 2888.

The Franklin Institute of the State of Pennsylvania, acting through its Committee on Science and the Arts, investigating the Composition of Super-Resistant Glasses invented by Doctor Eugene C. Sullivan and Mr. William C. Taylor, of the Corning Glass Works, Corning, New York, reports as follows:

The general composition of glass is one part alkali, one part alkaline earth and six parts of silica. This composition may be varied, soda, the common alkali being replaced by potash and such metals as lead and zinc being introduced to give different properties to the glass as desired. For example, flint glass contains lead, which raises the index of refraction and makes the glass easier to cut and this kind of glass is used for table ware. In the super-resistant glasses considered herein, all the alkaline earth and most of the alkali are replaced by boric oxid and a very small amount of alumina is added to make it work more easily.

The word "Pyrex," a trade-mark of the Corning Glass Works, is applied to various wares, among which are articles of certain of the glasses covered by United States Patents that have been granted to Doctor E. C. Sullivan and Mr. W. C. Taylor, both of whom are connected with the Corning Glass Works.

United States Patent No. 1,304,622 was issued on May 27, 1919 for a Heating Vessel. The specific use for which this was designed was a baking dish for the baking of bread, pies, etc. The requirements that must be met by a glass vessel for such use were not to be found in glass known to

the art prior to the inventions covered by the patents cited, since earlier glass was not resistant to chemical attack and had a comparatively high coefficient of expansion and low thermal endurance—thermal endurance being the ability to undergo sudden heating and cooling without fracture. What was required was a glass having a low coefficient of expansion so that it could be subjected to sudden changes of temperature without cracking, one that was highly resistant to chemical attack and that would not be acted on by acids. After a long series of experiments, boro-silicate glasses having these properties were developed with compositions such as the following:

	A.	*B.*	*C.*
(1) Silica	70%	80.6%	90%
(2) Boric oxid	20	13	6
(3) Sodium oxid	4	4.4	3
(4) Alumina	6	2	1

An inspection of this table of composition shows that it is free from heavy metals and from those of the magnesium-calcium-zinc group and is of simple chemical composition. It has a specific gravity of 2.25 and is number 7 on Moh's scale of hardness.

In all of these glasses the thermal endurance is high.

A measurement of the coefficient of expansion of Pyrex shows that it is less than that of other well-known glasses.

Since vessels of this kind must undergo high temperatures the softening point must be high. This is found at about 800° C. but at a slightly lower temperature the glass can be fashioned into a dish under pressure. This method of manufacture gives vessels free from surface checks, a most desirable result in a dish to be used for cooking.

By virtue of the low expansion coefficient of the glasses it is possible, without impairing thermal endurance to make the dishes thick-walled and therefore able to withstand blows or falls without breaking. It was discovered that food would bake in an oven in glass dishes more quickly than in metal. This is accounted for by the fact that glass absorbs most of the infra-red radiation of the oven while a metal dish reflects most of it. The comparatively high heat conductivity of the new glasses is also a favorable factor in this respect.

The following tests were made to determine the effect of heat shock: vessels containing 200 cc. of ice water were supported on Nichrome triangles and brought to the boiling point as rapidly as possible by the application of a Meker type burner. They were then plunged into ice water. Vessels containing 200 cc. of melted paraffin were heated on a hot plate to a temperature of about 160° C., then cooled to 150° C. and plunged into ice water. Vessels containing 200 cc. of melted paraffin were heated to about 215° C., cooled to 200° C. and then plunged into ice water.

Tests were also made to determine its resistance to mechanical shock. The results showed that this glass is of superior quality in both respects.

A second U. S. Patent, No. 1,504,623, is for "Glass" and places the emphasis upon its composition. Examples of different percentages are given including the three given in the former patent and the following:

	B_2.	D.	E.
SiO_2	80.9%	85	90
B_2O_3	12.9	12.5	5
Na_2O	4.4	1.5	—
Al_2O_3	1.8	—	2
Sb_2O_3	—	1	—
Li_2O	—	—	3

All the six glasses have certain desirable physical characteristics. They have a linear thermal expansivity less than 0.000004 between 20° C. and 300° C., glass of composition D having the least, 0.0000022. Their coefficient of heat conductivity is relatively high varying from 0.0028 calories per second per degree C. for each square centimeter of plate 1 cm. thick in A, B and B_2 to 0.0030 in C.

As an indication of the resistance of this glass to solution, an experiment is mentioned in which a glass of the composition B_2 was subjected to the action of distilled water at 80° C. for forty-eight hours and this lost only from .0001 to .0005 grams per 100 square centimeters exposed.

This glass is also characterized by being readily worked at the proper temperature. It becomes plastic at a temperature that can be obtained readily and hence can be pressed or blown into shape as desired. A thread of glass 1 mm. in diameter and 23 cm. long suspended vertically and heated

through its upper 9 cm. that will elongate by its own weight, at the rate of 1 mm. per minute when the temperature is 800° C. is said to have a hardness of 800.

It is seen that all these glasses have 70 per cent. or more of silica. It is also seen that the amount of alumina in each is low. This has previously been used in greater quantities in Boro-silicate glass to insure the ability to resist chemical attack and to prevent crystallization. Investigation has proved, however, that if the silica content is increased to above 84 per cent., which is possible while maintaining a low coefficient of expansion, the alumina content may be decreased to as low as 1 per cent. while the desirable qualities of chemical resistance and of remaining amorphous are retained.

The glasses sold under the Pyrex trade-mark are being extensively and successfully used in oven cooking utensils and the like, in flasks, beakers, test tubes and laboratory apparatus and in other applications in which their qualities make them of especial value for uses such as radio insulators, communication line insulators and more recently, high tension power line insulators.

In consideration of the noteworthy contribution to the art of glass manufacture, resulting in what is known as Pyrex, a glass that has desirable qualities both for domestic and scientific purposes, THE FRANKLIN INSTITUTE awards its HOWARD N. POTTS MEDAL to DOCTOR EUGENE C. SULLIVAN and MR. WILLIAM C. TAYLOR, of Corning, New York, jointly.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

AUTOMATIC RECORDING OF WAVES FROM BROADCAST STATIONS.

In the study of radio wave transmission phenomena the statistical method has proved useful in establishing the dependence of wave propagation on the various meteorological and geophysical phenomena. The degree and nature of this dependence is not yet certain, but systematic measurements at a distance over long periods of time are necessary. Such measurements in the broadcast frequency band are now being undertaken by various laboratories.

There has been developed at the Bureau of Standards a means for making regular continuous measurements of broadcast transmissions, and recording apparatus is in operation at the bureau's field station at Kensington, Md. A fixed vertical untuned antenna picks up the signal of a broadcast station and a superheterodyne receiving set changes its frequency to one in the intermediate range and amplifies it. The output of the receiving set is automatically measured and recorded on moving scaled paper by a commercial potentiometer recorder used in a three-electrode vacuum-tube peak-voltmeter circuit. Thus a curve is obtained showing the intermediate-frequency peak-voltage output of the receiving apparatus at each instant of time during the period of the record.

That the records so obtained may be relied upon as data for the study of transmission phenomena, it is necessary that both the radiating system and the receiving system remain substantially constant. Some broadcast stations employing piezo control of frequency and having their antenna currents carefully monitored are satisfactory as transmitters for this work. The constancy of the receiving system is checked daily by the use of a radio-frequency generator which is very carefully shielded and which provides small known radio-frequency voltages between two terminals. The records are calibrated in microvolts per meter, and the records with this

* Communicated by the Director.

calibration are therefore graphs of the variations with time of the field intensity of the broadcast signal at the receiving antenna. Differences between daily calibrations have been made very small by keeping the receiving set under temperature control and by taking proper care of voltage supplies and tubes.

The apparatus described has been used for several months to measure the daytime field intensity of one station. Recently the hours of recording have been extended to cover the entire transmitting hours of the station. In order to include both day and night field intensities in the same output scale a logarithmic relationship between the input and output of the receiving system is essential. This has been roughly attained by using a single stage of screen-grid amplification ahead of the superheterodyne receiving set and by having the potential of the screen grid controlled by the mechanism of the recorder in such a way as to reduce the amplification of the set as input voltages are increased. The present calibration of the output scale covers all but the highest signal peaks, and the records show the diurnal variations in the intensity of the signal.

No publications on this equipment are available as yet. When material on the subject is issued, it will be announced in these columns.

AIRCRAFT RADIO RESEARCH.

A number of improvements have been incorporated in the blind landing aids now under development by the Bureau of Standards at College Park, Md. The improvements are chiefly in the use of the runway localizing beacon. The use of this beacon, which serves to orient the pilot along the major axis of the field, so that he can land by means of the high-frequency landing beam, has previously proved difficult owing to the necessity for critical adjustment of the receiving set volume control as the airplane approaches the beacon transmitter. A device for automatically controlling the intensity of the receiving set output has been developed, which removes the necessity for volume control adjustments on the part of the pilot. This device rectifies the output voltage of the

receiving set and applies the rectified voltage on the grids of the radio frequency amplifying tubes, thereby automatically controlling the sensitivity of the receiving set to give constant signal output regardless of the input voltage to the set. A large number of ground and flight tests have proved the practicability of this device. To use the localizing beacon, the pilot needs only to change the tuning of the receiving set from the main beacon frequency to the localizing beacon frequency, and to observe the indications of the course indicating instrument.

Experiments were begun on a zero-center pointer type instrument to replace the vibrating reed indicator as a course indicator for the runway localizing beacon. The pointer swings to the left or right as the airplane deviates to the left or right from flight over the runway. This offers the advantages of giving the same sort of course indications with respect to the major runway as is given by the landing beam indicating instrument with respect to the proper gliding path for landing. Tests are now in progress to determine the relative advantages and disadvantages for the two types of course indicators for use on the runway localizing beacon.

From time to time during the past six months attention has been given to the development of a transmitting circuit arrangement for furnishing radiotelephone and visual type radiobeacon signals simultaneously on the same carrier frequency. A theoretical study of several possible circuit arrangements was made some months ago, and preliminary experiments were carried on using one particular arrangement, in which fairly successful results were obtained. The problem has been undertaken in a comprehensive way during the past month, a new transmitting circuit arrangement being set up which gives promise of overcoming the technical difficulties involved in this problem.

The problem is quite definite. The beacon modulation frequencies are all below 150 cycles, while intelligible speech does not require modulation frequencies below 250 cycles. The two sets of modulation frequencies may therefore be transmitted on the same carrier frequency, provided a properly designed transmitting circuit arrangement is employed. On the airplane an electrical filter circuit is necessary in the

receiving set output so that frequencies above 250 cycles are applied to the headphones and those below 250 cycles to the vibrating reed indicator.

A difficult problem is brought about by the necessity for providing much greater power radiation for the radiotelephone signals than is required for the radio range signals. Field intensity measurements made on existing radiotelephone and radio range beacon stations indicate field intensities for the radiotelephone station five to seven times as great as for the radio range station. The marked difference is due entirely to the difference in the antennas employed, the open type antenna used with the radiotelephone station being much more efficient than the loop antennas used with the radio range beacon.

The transmitting circuit arrangement (for the simultaneous furnishing of the two services) employed in the early tests contemplated the use of loop antenna transmission for both the radiotelephone and the radiobeacon signals. This had the advantage of requiring a minimum amount of change to the existing type visual radio range transmitter, but had the major disadvantage of not providing sufficient power radiation unless water-cooled vacuum tubes of higher power ratings could be employed. The new transmitting circuit arrangement now under development overcomes this difficulty and at the same time permits the use of the existing radiotelephone transmitters with very minor changes.

With this arrangement the carrier power and power for the speech side bands are supplied in the usual way by a 2 k.w. transmitter capable of about 75 per cent. peak modulation and feeding into an efficient open-type antenna. Ample radiotelephone power radiation is therefore provided. The master oscillator of the radiotelephone transmitter also serves as the master oscillator for the radiobeacon transmitter. The carrier wave is suppressed in the final power stages of the radiobeacon transmitter, the side bands only being transmitted by the loop antennas. The carrier necessary at the receiving end for beating with these side bands is supplied by the vertical antenna. Since the loop antennas transmit only side band, the power amplifier stages of the beacon transmitter may employ 500 watts (rather than 1 k.w. as

required in the present type beacon) and still supply ample power radiation.

On the airplane the simultaneous use of the two services may be still further simplified by means of the automatic volume control device. This device operates to maintain constant voltage across whatever portion of the output circuit it is connected. By connecting this device across the reed indicator terminals, constant reed deflections will obtain regardless of the distance of the airplane from the transmitting station. The average output signal in the head phones will bear a definite ratio to the voltage across the reed indicator, but is permitted to vary in instantaneous value so that variations in the sound intensity produced by changes in the speech modulation may be rendered with their true relative strength.

AËRODYNAMIC CHARACTERISTICS OF CIRCULAR-ARC AIRFOILS AT HIGH SPEEDS.

The aërodynamic characteristics of eight circular-arc airfoils at speeds of 0.5, 0.65, 0.8, 0.95 and 1.08 times the speed of sound have been measured in an open-jet air stream 2 inches in diameter, using models of 1 inch chord. A comparison with the measurements described in Technical Report No. 319 of the National Advisory Committee for Aëronautics shows that at speeds of 0.95 and 1.08 times the speed of sound the circular-arc airfoils are more efficient than airfoils of the R.A.F. or Clark Y families. At a speed of 0.5 times the speed of sound, the thick circular-arc sections are extremely inefficient but the thin sections compare favorably with those of the R.A.F. family. A moderate rounding of the sharp edges changes the characteristics very little and is in many instances beneficial. The results indicate that the section of the blades of propellers intended for use at high tip-speeds should be of the circular-arc form for the outer part of the blade and should be changed gradually to the R.A.F. or Clark Y form as the hub is approached.

This work will be described in a forthcoming technical report of the National Advisory Committee for Aëronautics.

RESISTANCE OF METALS, SUITABLE FOR DIES, TO THE ABRASIVE ACTION OF PLASTIC CLAY.

The purpose of this investigation is to obtain data on the "wearing qualities" of different metals and alloys under measurable conditions simulating those of the stiff mud process of forming clay products. The principal abrasive material in clay is "silica sand" which varies in amount from a fraction of one per cent. to more than 40 per cent. in different clays. Inasmuch as specimens composed of nickel, chromium, and tungsten which are very resistant to abrasion were included in the tests, it was desirable to "accelerate" abrasion by using a mixture of clay and quartz sand. Preliminary experiments with different proportions indicated that a mixture of 60 per cent. plastic Maryland clay and 40 per cent. quartz sand (passing 20 mesh) gave the most satisfactory results. The metal test specimens are made cylindrical in form, 7/8 inch in diameter and 1 inch in length, with a tapered orifice 1/4 inch in diameter at the egress end and 5/16 inch in diameter at the ingress end.

The clay-sand mixture is tempered with 15 per cent. of its weight of water, and a constant volume is extruded from the test specimen at a constant volume rate.

The extrusion pressures are read at half minute intervals and the length of column is metered as it issues. The abrasion loss is determined in grams by weighing the specimen before and after the test.

Up to the present time 12 metals and alloys have been tested. A comparison of the weight losses per unit volume of clay-sand mixture extruded is of interest. These are calculated on a basis of "unity" for the average of chromium-nickel-tungsten compositions which were most resistant to abrasion of the specimens tested.

The relative abrasive losses in weight are:

Carbon-cobalt-chromium	2.33
Average for several cast irons	30.96
Carbon-chromium-nickel steel	39.13
Electrolytic copper	161.00
Manganese-zinc bronze	276.80

The nitriding of steel produces a hardened "wear resisting" surface which decreases in hardness with depth. Four tests of such a steel were made on duplicate samples which gave the following comparable losses:

Test No.	Weight Loss.
1	8.20
2	10.12
3	12.50
4	15.36

It is seen that the abrasion loss increases with the removal of successive layers of the hardened surface. As wear progresses the abrasion loss approaches that of the softer untreated steel core.

DENSITY VS. COMPOSITION OF SODA-SILICA GLASSES.

In addition to a study of the relations between composition and index of refraction of glasses, similar studies are being made with respect to density. The same glasses used for index of refraction were also used for density determinations, and computations on the density-composition relations of a series of soda-silica glasses have been practically finished.

The glasses were melted in platinum and were made from chemically pure sodium carbonate and colorless, transparent, crystallized quartz. The composition of the 13 glasses used in this part of the study varied from 55 to 80 per cent. silica, the balance being soda. The glasses were annealed before tests were made, and computations were based on the composition determined by chemical analysis. Density determinations were made by weighing in kerosene at approximately 20° C.

Results indicate that the density of the soda-silica glasses in the given range of compositions can be computed from the expression:

$$D = 0.07977(86.5 - A)^{0.42107} + 2.203,$$

in which A is the percentage of silica present. Similarly the density can be computed from:

$$D = 0.00301B - \frac{2.988}{B - 1} + 2.4756,$$

in which B is the percentage of soda present.

Relations between composition and density of the soda-silica-lime glasses have not yet given such satisfactory results as those obtained for the index of refraction relations reported in Technical News Bulletin No. 155 (March, 1930).

PERMANENCE STANDARDS FOR PRINTING AND WRITING PAPERS.

In a paper presented by B. W. Scribner at the June, 1930, semi-annual meeting of the American Society of Mechanical Engineers as a part of the program of the printing industries session, suggestions are given on standardization of printing and writing papers in respect to their permanence qualities.

It is pointed out that such standards as are in use for the purpose are inadequate, as they are based primarily on fiber requirements which may have no relation to the aging quality of the papers. Through a review of the information available, including both laboratory studies and the history of the natural aging of papers, it is shown that the processing of the fibers and the care taken in the various paper-making operations are the important factors in determining how well papers will withstand deterioration. The strength of paper and its purity are dependent on these factors.

Papers must have sufficient strength to withstand the mechanical stresses incident to their use and must have sufficient purity, both cellulosic and non-cellulosic, to guard against chemical reactions that induce decomposition. The basic constituent of paper fibers is cellulose, which is one of the most permanent forms of matter known. Cellulose is very susceptible, however, to deterioration induced by impurities that may be associated with it and by some of the chemicals that are used in paper manufacture.

From these considerations a classification based primarily on strength and purity is suggested, which places printing and writing papers in four groups: (1) permanent papers, (2) papers having a minimum life of 100 years, (3) papers having a minimum life of 50 years, (4) papers for temporary use.

It is suggested that the various grades for all except the papers intended for temporary use be defined by limits for alpha cellulose, copper number, rosin, and acidity, as all of these properties appear to have an important bearing on

aging quality. A high content of alpha cellulose and a low copper number are considered the best known indications that the paper fibers have the basic purity required for long life. Minimum amounts of rosin and acid are desirable as these components are harmful to any fiber, no matter how pure it may be, if they are present in excessive amounts.

HEAT OF COMBUSTION OF LEATHER.

The problem of disposing of scrap leather has often resulted in its use as a fuel. Recent inquiries have been received as to the heat of combustion values for leathers and determinations have been made on two samples of leather typical of those used in the manufacture of shoes.

Ground leather, air-dry, was compressed into pellets weighing from 1 to 1.5 grams and burned in a bomb calorimeter. The results of the tests are given below.

Kind of Leather.	Insoluble Non-Combustible Ash. Per cent.	Heating Value. Btu. per lb.
Calf upper, chrome-tanned	5.3	7830
Sole, vegetable-tanned	1.2	8280

The heat of combustion values for leather will logically vary, and those which have high grease contents will have higher values than shoe leathers represented by these samples.

In determining whether it is more economical to burn or sell scrap leather, it appears only necessary to compare its heat and price values with those of other fuels.

AN AUTOMATIC BALANCE.

In the course of an investigation of the particle size of lime, it was desired to study the rate of settle of lime from a suspension in a liquid. To do this an automatic weighing device was set up. On one arm of a precision balance a small permanent magnet was suspended which hung down into a solenoid. On the other arm was hung a pan upon which the lime settled. The balance was then kept in equilibrium by controlling the current flowing through the solenoid. A

mirror mounted on the balance beam controls a photo-electric circuit which, through a relay and motor, controls the sliding contact in a rheostat in series with the solenoid. The resistance is thus maintained at such a figure that the balance remains in equilibrium all the time. A record of the current flowing through the solenoid can be changed into a weight time record which is necessary to calculate the particle size distribution of the lime. To check up on the performance of the balance, successive milligram weights were recorded through the electrical system as 1.01 ± 0.1 milligram.

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LIBRARY NOTES.

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BOOK REVIEWS.

REFLEXIONS SUR LA MECANIQUE ONDULATOIRE, UNE ANCIENNE THEORIE DYNAMIQUE ONDULATOIRE. Par E. de Camas. 98 pages, 8vo, paper. Paris, Librairie Scientifique Albert Blanchard, 1929. Price 14 francs.

There has been no lack of enthusiasm on the part of men of science in contributing to the literature of modern physical theory. Here we have an essay from the unusual viewpoint of a physicist who has recently resumed an interest in that field after an inactivity of twenty years. Modern physical theory has been under development already over a considerable term of years and the author himself participated in that movement no later than December 13, 1902 by the publication in the *Revue Scientifique* of a theory of undulatory mechanics conceived some five or six years earlier. This he discusses at length especially with reference to the notable investigations of L. de Broglie. The many other interrelated topics of atomic physics are also carefully surveyed. Of especial interest may be mentioned the account of a particular form of a tetrahedral arrangement of atomic weights in their relation to modern theory.

The work is a constructive document towards clarifying the methods of present day physics.

LES METHODES NOUVELLES EN ANALYSE QUANTIQUE (MECÂNIQUE QUANTIQUE. MECANIQUE ONDULATOIRE). Par Julien Pacotte. Docteur es Sciences. VII–139 pages, 8vo, paper. Paris, Librairie Scientifique Albert Blanchard, 1929. Price 22 francs.

Covering the same ground in general as the preceding essay, this work is rather an analytical presentation of the state of the art and its evolution in recent years than one of retrospectic comparison. As stated by the author, it is the synthesis of numerous memoirs which appeared during the period from 1925 to 1928. In a first division of the work the researches of Bohr, Heisenberg, Schrödinger, de Broglie and others who have taken a leading part in dealing with the modern conceptions of quantum mechanics are developed. A second part considers the researches which have followed the first memoires of Schrödinger, the adaptation of undulatory mechanics to relativist physics and the statistical conception of quantic mechanics. Works of this sort constitute another step toward the achievement of the unification of physical laws.

L. E. P.

LES RAYONS X (THÉORIE ET APPLICATIONS). Par Jean Thibaud, Docteur ès sciences, Ingenieur, E.S.E., Directeur-adjoint du laboratoire de Physique des Rayons X (École Pratique des Hautes Études). 218 pages, 16mo, paper. Paris, Librairie Armand Colin, 1930. Price 10 frs. 50.

Almost immediately upon the discovery of x-rays, their properties of penetrating opaque objects received widespread application which the course of time has proved them to be one of the most notable contributions of physical science to the immediate benefit of mankind. Subsequent study brings them new laurels as a most fertile method of investigation of atomic structure, and it is from the latter point of view that the author approaches the subject. In this timely

addition to the admirable series of remarkably informative monographs in compact form known as the "Collection Armand Colin," the author traces, from a consideration of the theory of matter and radiation, the fundamental properties of these rays.

The epochal work of Laue on the production of diffraction effects with x-rays by the use of crystalline gratings and the notable achievements of the Braggs, Compton and others are typical of the sort of material with which the book abounds. Continuing, we have an outline of atomic structure and the theory of spectra, photoelectric effect of x-ray and radiation of fluorescence and ionization by means of x-rays. Many of these it will be noticed are on general theory upon which x-rays have an incidental but highly important bearing. The subsequent part of the work deals with the technique and applications of the rays of which crystallography is of especial interest and with allied rays, those which approach the ultra-violet, gamma radiations, and the waves of de Broglie. The work is the substance of a lecture course conducted at the University of Louvain. The book contains a remarkably large amount of information in small space.

L. E. P.

STORAGE BATTERIES. A GENERAL TREATISE ON THE PHYSICS AND CHEMISTRY OF SECONDARY BATTERIES AND THEIR ENGINEERING APPLICATIONS. By George Wood Vinal, Physicist, Bureau of Standards, Member of American Institute of Electrical Engineers, Member of American Electrochemical Society. Second Edition, Rewritten and Reset, X–427 pages, 160 figures, 61 tables, 8vo. New York, John Wiley & Sons, Inc., 1930. Price $5.00.

There seems to be no doubt but what this book, recently rewritten and reset, leads the field of publications dealing with the subject of storage batteries. The author has prepared a treatise which successfully embraces all phases of the subject. A glance over the Table of Contents should dispel any doubt regarding this last statement.

Following a short introduction the author begins with a description of materials and methods of manufacture. There are two main types of storage cells: the lead-acid and the iron-nickel oxide-alkali or Edison type. Both of these are taken in turn.

The author seeks to indicate clearly the scientific and practical reasons for each particular step involved in the manufacturing process. Data upon the effects of impurities in the sulfuric acid which serves as an electrolyte, emphasize the importance of using an acid of great purity. Platinum, present to the extent of 3 parts in 10,000,000 effect the complete discharge of a battery. In the chapter on Theory of Reactions the author outlines the elementary theory of electric cells which assumes the presence of ions bearing definite electric charges and behaving in accordance with Faraday's law.

A wealth of evidence in support of the "Double Sulfate" theory also is included. Thermodynamical equations dealing with energy transformations and coefficients of voltage changes are briefly outlined. Following a chapter upon capacity and factors affecting the same we come to "Methods of Operation" which, from the practical standpoint, may be accorded the greatest importance. This chapter includes a thorough description of charging methods with accompanying circuit diagrams and graphs; procedures for the recording of operating

conditions and determining operation costs, directions for dismantling and assembly of lead-acid type cells; and possible sources of trouble. The efficiency of a battery is defined and directions are given for the making of capacity tests as well as those relating to mechanical strength, purity of materials and correctness of fabrication. A concluding chapter lists the present widespread applications of storage batteries and describes the peculiar characteristics necessary in each type so as to make it adaptable to that particular use.

Although described as a "General Treatise" this work will be found to be immensely valuable as a reference and handbook.

T. K. CLEVELAND.

THE AËRONAUTICS BRANCH OF THE DEPARTMENT OF COMMERCE. ITS HISTORY, ACTIVITIES AND ORGANIZATION. By L. F. Schmeckebier. 147 pages, 8vo. Washington, D. C., The Brookings Institution, 1930. Price $1.50.

This is No. 61 of the service monographs of the United States Government. It is well that the history of the government's activities in the early development of aëronautics should be set forth while those who took part in the initiatives are living. Legend no doubt will in later years grow up in connection with the matter and the accurate records will help in clearing out such mysticism. In a formal publication of this kind one cannot expect any philosophic discussion of the beginnings of the attempts to fly a heavier-than-air machine, long regarded as impossible, and efforts to such purpose deprecated by distinguished scientists. Necessarily no national organization could develop until aërial navigation was demonstrated as possible. Hence the story begins with the work of the Wright Brothers, Langley's painstaking, ingenious and self-sacrificing labors being unmentioned. In other works, however, Langley's merits will be set forth. The book contains a detailed account of the story of aviation as developed by the National government.

H. L.

LA PLANÈTE MARS. 1659–1929. By E. M. Antoniadi, Observatory of Meudon. Quarto, 239 pages, numerous illustrations in text and full-page plates. Hermann & Co., Paris, 1930. Price 80 francs.

Our nearest celestial neighbor ("Dictynna, goodman Dull") offers little opportunity for romantic speculation. The most powerful telescopes reveal nothing but desolation, with little if any atmosphere or water. The planet Mars, however, presents a tantalizing approximation to conditions on this earth. For several centuries, astronomers have been busy with the study of its markings and diversified colored areas. Imagination has been allowed too free range, and as a result, men who should have confined themselves to the collection of facts have endeavored to promote popular views as to the nature and methods of the "Martians," and have even gone so far as to suggest the possibility of establishing communication with them.

The present work is a purely scientific description of the surface of the planet embodying many years of study by the author, together with a comprehensive examination of the vast literature that has been produced since the telescope enabled us to study it with moderate satisfaction. The author is not carried away by any impulse to attract the newspapers or the unthinking public by discussing the origin and nature of the so-called "canals." To him the planet is

merely one of the members of the solar system to be studied with all the methods at command, checking and verifying all data, ignoring the speculative and sentimental tendencies that have adulterated Martian investigation in the last quarter-century.

The surface of Mars shows many curious markings differing in outline and color, although, as is well-known, the prevailing tint is distinctly red. Moderate telescopic power reveals a most striking and interesting feature—the polar caps. These seem certainly to be similar to snow if not actually such. They follow the seasonal changes of the respective poles, increasing in the winter period and diminishing in the summer, being located almost but not quite concentrically with the poles. They were discovered by Cassini in 1666. Other markings, the so-called "canals," have been the subject of much dispute. Our author's opinion concerning them is sufficiently expressed by the title of the chapter in which he discusses the subject "The Illusion of the Canals." It is not necessary to consider in detail the presentation of his views, but it is interesting to note that he makes no reference to the misrepresentation that has arisen in consequence of the erroneous translation of the work that the Italian astronomer (Secchi) used to designate a feature of areography (Antoniadi uses "areography" as the Martian equivalent of "geography"). Secchi applied the name to a conspicuous area, the "Dune sea" (Syrtis major) but later Schiaparelli applied the term to parallel markings that he had observed. Unfortunately, the Italian word "canali" which means "channels" and, therefore, indicates natural conditions, had been mostly rendered in English as "canals," which conveys the idea of artificial construction. Much of the Lowellian areography has received favor on account of this mistranslation. Sig. Antoniadi does not refer to this error, possibly because the French word "canal" is equivalent, according to a standard dictionary, to both "channel" and "canal." At any rate, he seems to ignore all the talk about the inhabitants of the planet.

The view that the polar caps are snow, generally held by astronomers, has not been universally accepted. It has been suggested that they may be deposits of carbon dioxid, but our author does not accept this view, and as he terms them always "neiges," we may safely assume that he regards them as identical in composition with our own winter-landscape covering. They appear only at the Martian poles.

The whole surface of the planet has been carefully studied and a large number of details shown in drawings, together with many full-page plates. The satellites are given a special chapter, but no allusion is made to the remarkable anticipation of this discovery by Swift in one of his Gulliver stories. The author presumably does not know the story and if he did would probably regard it as unsuitable for allusion in a strictly scientific work. Americans may be justly proud that the discovery of these two minute and somewhat eccentrically-behaving attendants on Mars was made by an American astronomer. As attendants on the God of War, they were appropriately given Homer's titles, Deimos and Phobos, "dread" and "fear."

The book is a splendid study of a very interesting member of our celestial system, and is written in the true spirit of science—a search for truth.

HENRY LEFFMANN.

CONFERENCES D'ACTUALITES SCIENTIFIQUES ET INDUSTRIELLES, ANNEE 1929. A series of monographs by L. de Broglie, G. Foëx, E. Block. L. Dunoyer, G. Ribaud, Lt. Colonel Jullien, L. Bloch, V. Kammerer and Rene Mesny, with a preface by J. Lemoine. VIII–271 pages, 8vo, paper. Paris, Librairie Scientifique Hermann et Cie., 1929. Price 5 francs.

It may not be possible for yet a long time to give a popular account, as that term is understood, of modern physical theory, not alone because it is still in the process of evolution but also because its interrelated phenomena do not lend themselves as readily to a simplified presentation as the natural philosophy of yesteryear. Nevertheless, that famous institution, the Conservatoire des Arts et Metiers which is maintained for the dissemination of scientific knowledge and the stimulation of industrial progress, in the issue of this work, makes a valuable contribution to that end. Some fifteen years ago, relates M. Lemoine, the Administrative Board decided upon a program of lectures on fundamental topics of science and some of their notable applications in industry. The dire events which began in 1914 compelled a postponement of this project until 1927 and since that year nine of these lectures, which are of a character suitable to the reader who seeks qualitative or general information, have been collected in this volume in order to bring them within the reach of others besides those who are identified with the activities of the Conservatoire.

A glance at the names of the authors of these monographs proclaims at once for them a high standard of informative value. Under the title "La crise récente de l'optique ondulatoire," Professor de Broglie makes a philosophic non-mathematical survey of the quantified undulatory theory of the mechanism of the propagation of radiant energy, with the evolution of which he has been so closely identified. Professor Foëx discusses "Les substances mésomorphes, leurs propriétés magnétiques," bodies which have assumed properties intermediate between those of the crystalline and amorphous state. Professor Bloch in "Les atomes de lumiere et les quanta," gives another angle of view on a subject kindred to that discussed by Professor de Broglie.

Of great interest are the forty-seven pages on the photo-electric cell and its applications by Professor Dunoyer. He considers the principles of its operation, the characteristics of current voltage, current against incident flux, the influence of the form of the cell, and other allied quantities. Among the applications are photometry, colorimetry and telephotography. Important matters of technique in the manufacture and operation of these cells are also included in this comprehensive outline. With the contribution of Professor Ribaud "Le rayonnement des corps incandescents.—Temperatures apparentes de brillance, de radiation et de couleur—Mesure optique des temperatures," we come to a consideration of a rational study of radiation, which thirty years ago in the hands of Professor Planck made such a notable contribution to present-day views.

Lieutenant Colonel Jullien has forty-eight pages in radioelectric oscillations and their applications to musical instruments. The extensive amount of research which has been applied to the production of musical sounds by electrical methods as chronicled in this contribution is perhaps not generally realized. The memory of Cahill's "telharmonium" upon which concerts were regularly given in New York City a quarter of a century ago still lingers, and Theremin's thermionic-tube musical instrument is of recent exploitation in this country as well as abroad. Both of

these devices are mentioned along with a number of others which are now fully described. The multiplex structure of spectral lines proved an unsolved problem until the work of Bohr in atomic structure and its development provided a solution. In a second paper, Professor Bloch with his usual clarity of treatment outlines the fundamental basis of atomic physics in "Structure des spectres et structure des atomes."

Something of a degression from the character of this series of papers occurs with the inclusion of M. Kammerer's contribution on "Les hautes pressions de vapeur." Boiler pressures, already many months ago, reached the high value of 1800 pounds per square inch. M. Kammerer examines at length by the use of the Mollier diagram the economies to be expected from these high pressures. Several novel forms of boilers adapted to high pressure are shown diagrammatically. The final paper by M. Mesny is on directed electromagnetic waves. "Les ondes dirigees et leurs applications." Here again the subject is treated descriptively.

The volume is of rare interest in supplying accurate descriptive information from the pens of authors of note on timely subjects of pure and applied physical science which are usually shrouded in a formidable array of mathematical analysis. Readers who wish to refresh their knowledge of fundamental theories of physics, or those who desire a sound general survey will not err in the perusal of this wisely chosen collection of papers.

LUCIEN E. PICOLET.

THE CONDENSED CHEMICAL DICTIONARY, compiled and edited by the Editorial Staff of the Chemical Engineering Catalog. Second edition, completely revised and enlarged under supervision of Thomas Gregory, Editor, Isabelle M. Welch, Assistant Editor. 551 pages, 8vo. New York, The Chemical Catalog Company, Inc., 1930. Price $10.00.

Although the present volume is only about half the size of the first edition, a large amount of additional information has been added to the work. This has been accomplished by using thinner paper and smaller type, changes that make for compactness and convenience for many users, but add to the troubles of the older chemists with poor eyesight. However, the great bulk of those who use the book will be the younger generation and to them it will be a welcome aid. From the preface we learn that the Information Bureau of the Chemical Catalog Company is kept busy answering questions of great variety and in the preparation of the book these questions have been valuable suggestions for the definitions to be included.

In the preparation of a book of this scope the greatest problem is what to exclude. Modern chemistry is overwhelmingly rich in new terms and in new meanings of old terms, and the preparer of a dictionary has certainly an "embarrassment of riches" (in available material). The book is practically prepared to be used in applied chemistry, a field wide enough to occupy much time and require much labor in selecting, arranging and defining the terms included. A very large amount of useful information along all lines of applied chemistry is to be found in the book and chemists in many specialties will welcome this new edition and consider it a timely addition to their libraries. The mechanical execution of the book is commendable, though the impression seems a little pale and it is a question whether a book of this size needs a thumb-index.

It is gratifying to note that now two excellent chemical dictionaries are available in English, one covering the general science and the other the extensive practical applications. The literature of chemistry is now so vast that condensations are urgently required. The dictionary form is especially convenient and reminds one of the old couplet,

> "Index learning turns no student pale,
> But holds the eel of science by the tail."

HENRY LEFFMANN.

NATIONAL ADVISORY COMMITTEE FOR AËRONAUTICS.

Report No. 345. The Design of Airplane Wing Ribs., By J. A. Newlin and George W. Trayer. 54 pages, illustrations, quarto. Washington, Government Printing Office, 1930. Price twenty-five cents.

In obtaining information for the design of truss and plywood forms, tests were made at the Forest Products Laboratory on many designs of wing ribs. Different types in various sizes were compared by means of these tests, in accordance with the request of the Bureau of Aëronautics, Navy Department. Many tests were also made on parallel-chord specimens of truss and plywood forms and on parts of wing ribs, such as truss diagonals and sections of cap strips. It was found that for ribs of any size or proportions, when they were designed to obtain a well-balanced construction and were carefully manufactured, distinct types are of various efficiencies. With ideal construction the truss comes first; second, a lightened and reinforced plywood type; third, a full plywood web type with stiffeners; fourth, a plywood web with lightening holes and no reinforcing; and fifth, a full web with no stiffeners.

Each type has its place in airplane design because manufacturing difficulties set up practical limits for the various types. For example, shallow trusses cannot be manufactured and assembled without great difficulty. Neither can a reinforced plywood truss be substituted for a full plywood type when to obtain maximum efficiency an excessively thin plywood must be used.

The results of the investigation are intended to warn the designer against faulty construction and to aid him in formulating rules regarding the effect of various factors on the design and the strength of different parts.

Report No. 347. A Method of Calculating the Ultimate Strength of Continuous Beams. By J. A. Newlin and George W. Trayer. 28 pages, illustrations, quarto. Washington, Government Printing Office, 1930. Price ten cents.

In the design of continuous beams subjected to transverse load only, it has been common practice to estimate maximum loads by substituting the numerical value of the modulus of rupture, as obtained in bending tests, in the usual equation of three moments. Further, for combined axial and transverse loading, two methods of calculation have been used. The more common one is the application of the generalized equation of three moments, while the other is an extension of the ordinary equation of three moments to allow for the moments introduced by the direct tension or compression load. In the second method, the deflection in the

span at the point of maximum moment is calculated, neglecting the effect of axial load, and the product of the axial load and this deflection is added to the moment determined by the ordinary equation of three moments.

Both of these methods are used to calculate maximum loads, although neither is properly applicable beyond the elastic limit. The purpose of the study reported here was to investigate conditions after the elastic limit has been passed. As a result of the study, a method of calculation, which is applicable to maximum load conditions, has been developed. The method is simpler than the methods now in use and it applies properly to conditions where the present methods fail to apply.

The experimental work was conducted at the Forest Products Laboratory in coöperation with the Bureau of Aëronautics, Navy Department, and submitted to the National Advisory Committee for Aëronautics for publication. Over 300 continuous beams were tested under transverse load and under combined axial and transverse load. Loads obtained in test for beams of rectangular section were as much as 50 per cent. in excess of loads calculated by the usual methods, with the average about 25 per cent. For I beams the average increase was about 40 per cent. Fortunately, the error in the usual calculation is on the side of safety, but it is too great to be neglected in good design.

R.

PUBLICATIONS RECEIVED.

La Planète Mars. Étude basée sur les résultats obtenus avec la grande lunette de l'Observatoire de Meudon et exposé analytique de l'ensemble des travaux exécutés sur cet astre depuis 1659, par E. M. Antoniadi. 239 pages, illustrations, plates, quarto. Paris, Librairie Hermann et Cie., 1930. Price 80 francs.

The Theory of Potential, by William Duncan Macmillan, Ph.D. First edition. 469 pages, illustrations, 8vo. New York, McGraw-Hill Book Company, Inc., 1930. Price $5.00.

The Condensed Chemical Dictionary. A reference volume for all requiring quick access to a large amount of essential data regarding chemicals, and other substances used in manufacturing and laboratory work. Compiled and edited by the Editorial Staff of the Chemical Engineering Catalog, Francis M. Turner, Editor. Second edition, completely revised and enlarged. 551 pages 8vo. New York, The Chemical Catalog Company, Inc., 1930. Price $10.00.

Institute for Government Research. Service Monographs of the United States Government No. 61. The Aëronautics Branch Department of Commerce, Its History, Activities and Organization, by Laurence F. Schmeckebier. 147 pages, 8vo. Washington, The Brookings Institution, 1930. Price $1.50.

American Standards Year Book, 1930. 104 pages, quarto. New York, American Standards Association, 29 West 39th Street, N. Y.

Transactions of the American Geophysical Union, Tenth Annual Meeting, April 25 and 26, 1929, Eleventh Annual Meeting, May 1 and 2, 1930. 314 pages, illustrations, maps, 8vo. Washington, D. C., National Research Council, 1930.

Lecons sur la Resistance Des Fluides Non Visqueux, Professees par Paul Painleve, Premiere partie redigee par A. Metral. 183 pages, illustrations, 8vo. Paris, Gauthier-Villars et Cie, 1930. Price 40 francs.

Demag News, Special Edition for the World Power Conference, Berlin, June 1930. 68 pages, illustrations, quarto. Duisburg, Demag, Aktiengesellschaft, 1930.

Carte Geologique du massif Du Mont-Blanc (Partie Francaise), A L'Echelle du 1/20,000, par MM. Paul Corbin et Nicolas Oulianoff. Feuille: Vallorcine. Notice Explicative, 15 pages, illustrations, maps, 8vo. Saint-Maur-des-Fosses, G. Jacquart, 1930. Price 20 francs.

Four Maps Indicating Main Automobile Roads between Canada and United States. Four sheets, Ottawa, Government Printing Office, 1930.

National Advisory Committee for Aëronautics. Technical notes: No. 342, Identification of Aircraft Tubing, by Horace Knerr. 8 pages, plates, quarto. Washington, Committee, 1930. No. 343, Strength in Shear of Thin Curved Sheets of Alclad, by George Michael Smith, 27 pages, plates, quarto. Washington, Committee, 1930. No. 344, Performance of a High-Speed Compression-Ignition Engine Using Multiple Orifice Fuel Injection Nozzles, by J. A. Spanogle and H. H. Foster, Langley Memorial Aëronautical Laboratory. 18 pages, plates, quarto. Washington, Committee, 1930. No. 345, The Prevention of the Ice Hazard on Airplanes, by William C. Geer and Merit Scott. 23 pages, plates, quarto. Washington, Committee, 1930.

CURRENT TOPICS.

The Undulatory Nature of the Electron. LOUIS DE BROGLIE. (*Rev. Scientifique*, Jan. 11, 1930.) This is the address delivered by Louis de Broglie in Stockholm on December 11, 1929, at the occasion of the conferring upon him of the Nobel Prize in physics.

When in 1920 he resumed his interrupted studies in theoretical physics he was drawn toward this particular field of the science by the mystery that more and more was enveloping the structure both of matter and of radiations as the strange quantum conception introduced by Planck in 1900 permeated the whole domain of physics. To explain the development of his thought he sketches the difficulty at that time confronting physical theories. The corpuscular theory of light, enunciated in antiquity and maintained by Newton, was finally discarded in favor of the undulatory theory as a result of the work of Thomas Young and Augustin Fresnel on interference. Though the idea of atomic structure was from the time of these men onwards rejected in the field of optics it achieved excellent results elsewhere, as in chemistry and in the kinetic theory of gases. Later the investigations of Sir J. J. Thomson made it necessary to recognize particles of electricity. "Thirty years ago physics found itself divided into two parts. On one side was the physics of matter based on the conception of corpuscles and atoms that were supposed to obey the classical laws of Newtonian mechanics. On the other side was the physics of radiation proceeding from the idea of the propagation of waves in a continuous hypothetical medium, the luminous and electromagnetic ether. These two physics, however could not remain strangers to each other. It was needful to unite them in framing a theory of the exchange of energy between matter and radiation and it was just there that difficulties burst forth. In seeking to reconcile the two physics conclusions that were inexact and even inadmissible were reached on the subject of the equilibrium of energy between matter and radiation in a thermally isolated enclosure. It was coming to be said that matter ought to give up all its energy as radiation and in consequence tend of itself toward the absolute zero of temperature. It was necessary to avoid this absurd conclusion at any price. In an intuition of genius Planck saw the way to avoid it. Instead of admitting, as the classic theory of waves does, that a source of light emits its radiation in a continuous manner, it must be emitted, on the contrary, in equal and finite quantities, i.e., by quanta. The success of Planck's ideas has brought on grave consequences. If light be emitted by quanta, should it not, once emitted, preserve a granular structure? The

existence of quanta of radiation leads back then to the corpuscular conception of light. From another quarter it can be proved, as Jeans and H. Poincaré did, that if the movement of material particles in sources of light take place according to the laws of classical mechanics, it would be impossible to derive the exact law of black radiation, Planck's law. It is necessary, then, to admit that the old dynamics, even when modified by Einstein's Theory of Relativity, is incapable of giving an account of minute motions."

The photoelectric effect has confirmed the granular structure of light and other radiations. A beam of light or of X-rays incident on a piece of matter causes it to send out into the adjacent space electrons in rapid motion. The kinetic energy possessed by these electrons increases linearly with the frequency of vibration of the incident radiation but does not depend on its intensity. This is hard to explain if there is a constant stream of radiation falling on the irradiated body but can be understood if energy comes in parcels of quanta each of which is absorbed by one electron. The larger the number of quanta, that is, the greater the intensity of the incident light, the more numerous will be the emitted electrons, but the velocity of emission will be quite independent of the number of emitted electrons. Thus the way leads to Einstein's theory of quanta of light, proposed in 1905, and Newton's corpuscular theory is found again. In 1922 came Arthur Compton's discovery of the phenomenon of x-ray diffusion to add weight to the quantum theory of light. There, was however, no way of explaining the diffraction and interference of light save by the wave theory, and there was no way of reconciling the wave theory with the existence of light quanta. After the theoretical investigations of Planck and Bohr there was the further impossibility of seeing why an electron could revolve about an atomic nucleus only in certain privileged orbits and not in all orbits possible according to classical mechanics.

When de Broglie reflected on these unfortunate conditions in physics he was struck by the manner in which the quantity of energy in quantum of radiation is specified as the product of the frequency of the radiation multiplied by a physical constant known as Planck's constant. It is inconsistent that a corpuscular theory should require knowledge of a periodicity. Again, whole numbers are used in fixing the orbits possible to electrons and whole numbers are of rare occurrence in physics. They show themselves in connection with vibratory motion. "This suggested to me the idea that electrons themselves could not be represented as simple corpuscles but that there should, in addition, be attributed to them a periodicity. Thus I arrived at the idea of the following general effect that has directed my researches. It is necessary, as well for matter as for

radiations, especially for light, to introduce at the same time the idea of corpuscles and that of waves. In other terms we must in one case as well as in the other admit the existence of corpuscles accompanied by waves. But, since corpuscles and waves cannot be independent, since they constitute according to Bohr two complementary faces of reality, we should be able to establish a certain parallelism between the motion of a corpuscle and the propagation of the wave associated with it. The first end to be attained was then to set up this correspondence."

de Broglie enters upon a mathematical discussion of the relations between waves and corpuscles free from external action and derives simple equations connecting mass with frequency and, again, momentum with wave-length. The group velocity of waves is equal to the velocity of the particle. Further in a field of force derived from a potential function he shows that Fermat's principle in optics is correlative to Maupertuis' principle in mechanics. The prevalence of whole numbers in expressions for determining stable orbits for electrons follows from de Broglie's theory. "The conditions of quantic stability appear then as analogous to the phenomena of resonance and the appearance of whole numbers becomes as natural here as in the theory of vibrating strings and plates."

"To sum up the significance of wave mechanics, we can say this. To every corpuscle a wave must be associated and only the study of the propagation of the wave can furnish information regarding the successive localizations of the corpuscle in space. In large scale common mechanical phenomena the foreseen localizations are situated along a curve, the trajectory in the classic sense of the word. But what happens if the wave is not propagated according to the laws of geometrical optics, if, for example, there is interference or diffraction? We cannot then attribute to the corpuscle a motion in conformity to classical dynamics, that is certain. Can we still suppose that at each instant the corpuscle occupies in the wave a definitely determined position and that the wave in its propagation carries the corpuscle along as a billow transports a cork? All that I will say about it here is that there is at present a general tendency to admit that it is not constantly possible to attribute to a corpuscle a well defined position in the wave and that an affirmation should not go beyond this: 'When an observation is made permitting the localization of the corpuscle, we are always led to attribute to it a position in the interior of the wave and the probability of its being in a certain point M of the wave is proportional to the square of the amplitude at M, that is, to the intensity there.' "

X-rays are diffracted by crystals. The calculated length of the waves corresponding to electrons that have acquired their velocities

by falling through some dozens of volts is of the same order as the lengths of x-rays. Hence it seemed worth while to test the correctness of the equivalence of electrons to waves by seeing whether crystals would diffract electrons. Davisson and Germer in New York were the first to observe this effect. G. P. Thomson of Aberdeen has established the diffraction of electrons by thin films of metal. Still further confirmation came by the use of diffraction gratings. Compton and J. Thibaud were able to use these with x-rays in spite of the largeness of the rulings in comparison to the length of the waves by the device of letting the rays fall on the grating at grazing incidence. When Rupp in Germany substituted electrons for x-rays he obtained similar results and was thus enabled to measure the lengths of the electronic waves, just as the lengths of visible light waves are got from the diffraction grating.

"To describe the properties of matter as well as those of light it is necessary to speak at the same time of waves and of corpuscles. The electron can no longer be regarded as a simple little grain of electricity. We must associate a wave with it and this wave is not a myth because we can measure its length and predict its interference effects. A whole class of phenomena have thus been foreseen before they were actually discovered."

G. F. S.

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